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TARDAEWETHER Kellen * ODOE

From: Albrich, Elaine <ElaineAlbrich@dwt.com>
Sent: Friday, May 22, 2020 3:30 PM
To: TARDAEWETHER Kellen * ODOE
Cc: ESTERSON Sarah * ODOE; WOODS Maxwell * ODOE; David Brown; Michelle Slater; Albrich, Elaine; Bainter, Allison
Subject: Obsidian - Response to ODFW DPO Comments
Attachments: Obsidian_ODFW Response_Attachment 1_OSC_habitat_mitigation_plan_022120 _final_revised_05142020.docx; Obsidian_ODFW Response_Attachment2_WLIP lease.docx; Obsidian_ODFW Response_Attachment 3_Supplemental Evidence for Juniper Mitigation.docx; Obsidian_ODFW Response Attachment 4_OSCAPP WLIP Pre-Treatment Juniper Survey _Final_05202020.pdf; Obsidain_ODFW Response_Attachment 5_OSCAPP WLIP Juniper Treatment Plan_Final_05202020.pdf; Obsidian_Response to ODFW DPO Comments_05222020.pdf

Hi –

On behalf of Obsidian Solar Center, LLC (Applicant) please find attached the response to ODFW's DPO comments (April and May letters). Please let us know if you have questions. Hopefully this response goes a long way to addressing ODFW's issues. We will be preparing our technical consultants to testify at the DPO in addition to these written responses.

The following is attached:

- Obsidian response letter - PDF
- Attachment 1 (Redline of HMP in response to ODFW comments w/o Attachments) - Word doc
- Attachment 2 (Working Lands Improvement Program Agreement – Attachment 1 of HMP) – Word doc
- Attachment 3 (Supplemental Evidence of Juniper Mitigation) – Word doc
- Attachment 4 (Pre-Treatment Juniper Field Survey Report) - PDF
- Attachment 5 (Juniper Treatment Plan) - PDF

This is a large submittal so I will confirm receipt after I send. We will also send you a dropbox with the entire submittal in a single PDF.

Thank you for your continued work on this project. Elaine

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Anchorage | Bellevue | Los Angeles | New York | Portland | San Francisco | Seattle | Washington, D.C.

May 22, 2020

VIA EMAIL

Kellen Tardaewether
Senior Siting Analyst
Oregon Department of Energy
550 Capitol Street NE
Salem, OR 97301

Re: Response to ODFW Comments on Draft Proposed Order for Obsidian Solar Center

Dear Kellen:

Obsidian Solar Center LLC ("Applicant") provides this letter in response to the Oregon Department of Fish and Wildlife's ("ODFW") comments on the Draft Proposed Order for Obsidian Solar Center ("DPO"), dated April 24, 2020 ("ODFW Letter"). We have tried to respond issue by issue where we felt needed; other comments are noted but not addressed in this letter.

Big Game Winter Range and Habitat Classification

Applicant's Habitat Management Plan ("HMP") recognizes that the Facility site boundary is located on land mapped by ODFW as big game winter range, which ODFW treats as Category 2 under its Fish and Habitat Mitigation Policy ("ODFW mitigation policy"). The HMP proposes mitigation under Option 3 that satisfies the Category 2 mitigation obligation of "no net loss of habitat quantity or quality" and "net benefit to habitat quantity or quality" by implementing the Working Lands Improvement Program ("WLIP") on rangeland of similar quality to the Facility site and within proximity to the site. Applicant does not believe that there is confusion over how Applicant has described habitat under the ODFW mitigation policy. Other projects have used a similar approach to describe habitat that is located with ODFW-mapped big game range (Category 2) but may have habitat qualities similar to lower classes of habitat (Categories 3-6).

While Obsidian maintains that this approach is an appropriate and accurate way to inventory habitat under the ODFW mitigation policy, Obsidian accepts ODFW's recommendation.

Action: Obsidian will delete references to "Habitat Category based on Field Habitat Assessment" of Tables 1 and 2 in the HMP, as shown in the revised HMP (Attachment 1). Obsidian also withdraws its suggested redline to the DPO (which was to include "Habitat Category based on Field Habitat Assessment").

Mitigation Options in HMP
Obsidian wants to keep Option 1 and Option 2 in the HMP as placeholders for future discussion but revises the HMP to address ODFW's recommendation. Obsidian's redline comments on the DPO are consistent with this change in the HMP.

Action: Revise the HMP to document that Option 1 and Option 2 are not mitigation pathways available to Obsidian unless Obsidian amends the HMP. The revised HMP reflects this change.

HMP Option 3 – Working Lands Improvement Agreement
Obsidian will enter into a Working Lands Improvement Agreement ("Agreement") with property owners to implement the HMP and Working Lands Improvement Program ("WLIP") on mitigation properties identified in the HMP. The Agreement contains the substantial components described in the ODFW Letter: mutual commitments from property owner and Obsidian to maintain property per the HMP (e.g., Recitals, Section 1, Section 5, Section 6-8, Section 17); identifies permissible and prohibited (conflicting) uses (Section 5); establishes a term for the life of the Facility (Section 2); and access rights for ODFW and ODOE (Section 7). Obsidian objects to ODFW's assertion that the agreement must provide for third party monitoring and enforcement. Obsidian responds to this point more fully below. Obsidian will record copies of the Agreements in the real property records of Lake County.

Action: A draft of the WLIP Agreement is included as Attachment 2.

HMP Option 3 – Third Party Monitoring and Enforcement
Under the WLIP and HMP, Obsidian has monitoring and reporting obligations to ODOE and ODFW. Obsidian will contract with a third party to conduct the monitoring and help prepare the reports. Obsidian will file these reports with ODOE and ODFW. ODOE is responsible for enforcement under the EFSC Site Certificate and if ODOE, in consultation with ODFW, suspects a compliance question, ODOE (and ODFW) have the right to enter the mitigation properties to inspect the mitigation work. In addition, under the EFSC Site Certificate conditions, Obsidian is responsible for ensuring that its contractors are qualified and must provide ODOE evidence of such. For these reasons, Obsidian maintains that no third-party monitoring or enforcement is required. Nonetheless, Obsidian has already committed in Step 4 of the HMP, to engage Lake County Cooperative Weed Management Area (Lake County CWMA) to monitor the mitigation properties for noxious weeds and treat as needed.

HMP Option 3 – Life of the Facility
The HMP provides that Obsidian will implement the WLIP for the "life of the Facility," which is anticipated to be around 30 years but may be up to 40 years. Under the EFSC Site Certificate, at the end of the Facility's life, Obsidian is obligated to decommission and retire the Facility consistent with the EFSC Retirement and Financial Assurance Standard. Within two years following cessation of Facility operation, the certificate holder must apply to EFSC to terminate the Site Certificate pursuant to OAR 345-027-0110. In the application, the certificate holder must include a retirement plan. The requirement plan must include "[a] description of actions the certificate holder proposes to take to restore the site to a useful, non-hazardous condition, *including information on how impacts to fish, wildlife and the environme*nt would be minimized during the retirement process. OAR 345-027-0110(5)(b) (emphasis added). Obsidian conducted

a review of recently approved or amended EFSC projects and none have mitigation obligations like what ODFW is proposing for the Facility's decommissioning. Obsidian incorporates by reference its comments and analysis on this issue from its DPO comment letter, dated April 30, 2020.

Mitigation Risks, Ratios, and Monitoring

Obsidian acknowledges ODFW's comments concerning mitigation risks, ratios, and monitoring and responds as follows:

- The Category 2 habitat impact from Facility's permanent footprint totals up to 3,588 acres (depending on the Facility's final design).

- Obsidian proposes to increase the mitigation ratio from 1.1 to 1.2 in response to ODFW's comments. Obsidian maintains that a 2:1 mitigation ratio is not required to satisfy the Category 2 mitigation goal under the ODFW mitigation policy. The acreage selected for the WLIP program has good habitat value, no weeds of concern, and offers enhancement opportunities with the juniper removal and weed management measures. Juniper removal alone is a proven reliable method for habitat enhancement. The risk of failure to remove the juniper and maintain the treatment outcome is remote. See Attachment 3 for supplemental, third-party evidence supporting this conclusion. See also Obsidian's response to ODFW's supplemental letter dated May 18, 2020 below.

- The purpose of the WLIP is to provide mitigation by maintaining and improving big game winter on the mitigation properties. Winter range will be maintained by establishing the WLIP Agreement with the landowners. Big game winter range will be improved by providing a mosaic of vegetation associations designed to provide big game cover and forage areas across the acres enrolled in the WLIP. As described in the *Pre-Treatment Juniper Field Survey Report* (Attachment 4), and further developed in the *Juniper Treatment Plan* (Attachment 5), the actions under the HMP are designed to manage winter habitat quality on the mitigation properties, seeking to improve the forage quality and provide thermal and hiding cover for wintering big game. Therefore, all acreage enrolled in the WLIP are mitigation acres, not only the acres where juniper is removed.

- Obsidian conducted a desktop and field survey of the mitigation properties to confirm that the habitat targeted for protection and enhancement meets the "in-kind" requirement and has uplift potential. See the "*Juniper Phase Mapping Technical Memo*" prepared by Stantec (January 2020) included in the HMP; the "*Desktop Habitat Mapping Technical Memorandum*," prepared by Stantec (February 2020) included in the HMP; and the "*Pre-Treatment Juniper Field Survey Report*" prepared by Foster Consulting (May 2020) included as Attachment 4 to this letter.

- Obsidian will enter into WLIP Agreements with the property owners of the mitigation properties to protect habitat from development for the life of the Facility. The WLIP Agreements will cover at least 4,306 acres. Each WLIP Agreement is a recorded, enforceable agreement with restrictive covenants that protect the habitat from development for the life of the Facility. This type of agreement is a reliable method for protecting habitat

for a defined term (see discussion above and Attachment 2). Obsidian maintains that the acreage needed to satisfy the *no net loss* prong of the Category 2 mitigation goal is equivalent of the Facility's footprint based on the Facility's final design (estimated at up to 3,588 acres). Obsidian proposes to secure and protect more than 3,588 acres. For these reasons, ODOE may find that the proposal meets the "*no net loss of habitat quantity or quality*."

- Obsidian will implement the habitat enhancement portion of the WLIP across 4,306 acres secured under the WLIP Agreements. The juniper treatment plan proposes to remove juniper in phase 1, early phase 2, and phase 2 standards in order to retard juniper encroachment and its effect on understory vegetation, and retain juniper in pre-settlement and/or late phase 2 or phase 3 stands to provide cover. See the "*Juniper Treatment Plan*," prepared by Foster Consulting (May 2020) included as Attachment 5 to this letter. The reliability of juniper treatment and removal is proven as a reliable habitat enhancement measure, as discussed in provided plans and the studies in Attachment 3. The WLIP Agreement restrict the property owners' use of the mitigation property to ensure the success of the habitat enhancement for the life of the Facility. For these reasons, ODOE may find that the proposal provides a "*net benefit of habitat quality*."

- Obsidian will hire a qualified contractor (and/or engage Lake County CWMA) to conduct monitoring as provided in Steps 4 and 5 of the HMP and as further described in the *Juniper Treatment Plan* (Attachment 5). The success of juniper treatment and removal is relatively high and there were no weeds of concern identified on either mitigation property, as reported in the *Pre-Treatment Juniper Field Survey Report* (Attachment 4). In addition, measures are proposed in the *Juniper Treatment Plan* to minimize the risk of weed contamination during treatment. Obsidian proposes to have Lake County CWMA conduct annual noxious weed monitoring in treated areas for the first two years after juniper treatment (and annually for 3 years in areas reseeded following burning of slash piles).

Juniper Treatment Plans – Reducing Risk of Noxious Weed Infestation

The *Juniper Treatment Plan* (Attachment 5) contains best management practices ("BMPs") to avoid and minimize the risk of noxious weed introduction into juniper treatment areas. Obsidian has referenced these BMPs in the revised HMP (Attachment 1). As proposed in the *Juniper Treatment Plan*, areas where slash treatment was burned will be reseeded with a grass/legume mix and monitored for three years following the burn. Obsidian has updated the monitoring sections of the HMP to account for proposed measures in the *Juniper Treatment Plan*.

The areas of burn using Treatment 2 or 4 (as described in the *Juniper Treatment Plan*) are unlikely to be dense enough to warrant deferred grazing. There is unlikely to be burns with Treatment 1. The landowners manage their properties under grazing management plans and besides limiting grazing to existing levels over the life of the WLIP, Obsidian is sensitive to imposing further restrictions on the grazing as the program is mean to keep working lands working. For these reasons, Obsidian will not ask WLIP landowners to defer grazing for two years following juniper treatment.

Pygmy Rabbits

Obsidian proposed revised findings and revisions to Condition 9 in the DPO. Now, after receiving ODFW's comments on Condition 9, Obsidian proposes a new Condition 9 in response to ODFW's comments and withdraws its earlier comments regarding Condition 9.

Recommended Fish and Wildlife Habitat Condition 9: The certificate holder shall:

a. No more than 3-years prior to construction of the facility, conduct pygmy rabbit *(Brachylagus idahoensis)* surveys within the portion of the site boundary inside the perimeter fence, based on the final design of the facility, using the same protocol approved for the pygmy rabbit surveys conducted as a part of Exhibit P of the application for site certificate. The pygmy rabbit surveys shall also document presence of white-tailed jackrabbits (*Lepus townsendii).*

b. Use the results of the pygmy rabbit surveys under subpart (a) to minimize potential impacts to pygmy rabbits during construction by implementing a 3-meter (10 foot) buffer area around identified burrow complexes for construction activities between January 15 and June 15 (pygmy rabbit breeding period) unless a lesser buffer is approved by the Department in consultation with ODFW.

c. Avoid impacts to the previously identified complexes shown on ASC Figure Exhibit P-1 and identify the avoided areas on pre-construction figures.

Obsidian would agree to perform a pre-construction survey for pygmy rabbits if construction began later than three years from the prior pygmy rabbit survey and the results of the survey would be used to inform the minimization measures implemented during January 15-June 15 construction activities. In addition, as previously committed, Obsidian would avoid impacts to previously identified pygmy rabbit burrows and document avoidance during pre-construction compliance.

ODFW May 18th Comment Letter

In a letter dated May 18, 2020, ODFW provided comments in response to Obsidian's comments on the DPO. ODFW misconstrues Obsidian's DPO comments and incorrectly assumes that Obsidian is asking ODOE to apply the findings and conditions from the Bakeoven project. ODFW's May 18 letter is full of hypotheticals about the similarities and differences between the Obsidian and the Bakeoven sites and what "ODFW "would have done" had the Bakeoven project been "functioning as native, intact shrub-steppe." All that is irrelevant and ODOE should disregard it. This is not an exercise in compare and contrast. Referencing the Bakeoven project was to illustrate that ODOE does not always require a 2:1 ratio for big game winter range mitigation. Further, the reference was to illustrate tighter findings and the structure of findings. It was not to imply that the two sites were similar. That should be clear from Obsidian's commentary.

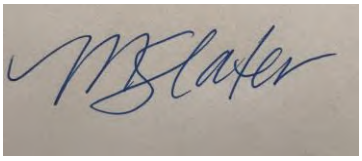
Obsidian maintains that a 1.2:1 ratio is appropriate and sufficient to satisfy its Category 2 mitigation obligations because of site-specific conditions within the Facility site boundary and

across the mitigation properties. The Facility site boundary is comprised of about 94 percent sagebrush shrubland. This habitat type, however, varies in cover, plant heights, and level of disturbance. Big sagebrush covers about 15 to 30 percent of the site boundary but up to 40-60 percent of the cover in the sagebrush shrubland is bare ground and there is evidence of cattle grazing in the big sagebrush (although damage was not extensive). See Attachment P-1, pg 9.

Obsidian's habitat enhancement program is robust and uses a proven and successful method (juniper removal) for enhancing sagebrush shrubland. ODFW raise success rates in its April 24 letter, noting that sagebrush vegetation restoration has a documented failure rate of around 80 percent but then ODFW goes on to note that the success rate for juniper removal is much higher. Obsidian reiterates that the mitigation proposal under the HMP is a juniper removal, habitat enhancement program to improve forage and thermal cover for big game. It does not propose sagebrush vegetation restoration as a specific criterion for successful mitigation. The mitigation properties have documented habitat enhancement potential that will benefit big game by improving forage and thermal cover. The ODFW mitigation policy defines "net benefit" as "an increase in overall in-proximity habitat quality or quantity after a development action and any subsequent mitigation measures have been completed and monitored." There is no numeric requirement for demonstrating "net benefit." For Option 3 to be successful, there only needs to be an overall "increase" in the habitat quality. The Pre-Treatment Juniper Field Survey Report (Attachment 4) and the Juniper Treatment Plan (Attachment 5), together with the weed management and monitoring, demonstrate that Obsidians' proposal can meet this net benefit threshold. In other words, Obsidian maintains that implementing the WLIP on 20 percent more land that that impacted by the proposed facility, will result in "an increase in overall" habitat quality across the mitigation property.

Thank you for your continued work on this project.

Very truly yours,



Michelle Slater
Obsidian Renewables LLC

Enclosures

cc: David W. Brown
Elaine Albrich

Obsidian Solar Center LLC

Obsidian Solar Center

Habitat Mitigation Plan

May ~~February~~ 2020

Obsidian Solar Center LLC

5 Centerpointe Drive, Suite 250
Lake Oswego, Oregon 97035

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ATTACHMENTS

Attachment 1 ~~Template~~ Working Lands Improvement Program Agreement ~~Easement~~ ~~[*Submitted Under Separate Cover*]~~

Attachment 2 Juniper Phase Mapping Technical Memo

Attachment 3 Desktop Habitat Mapping Technical Memorandum

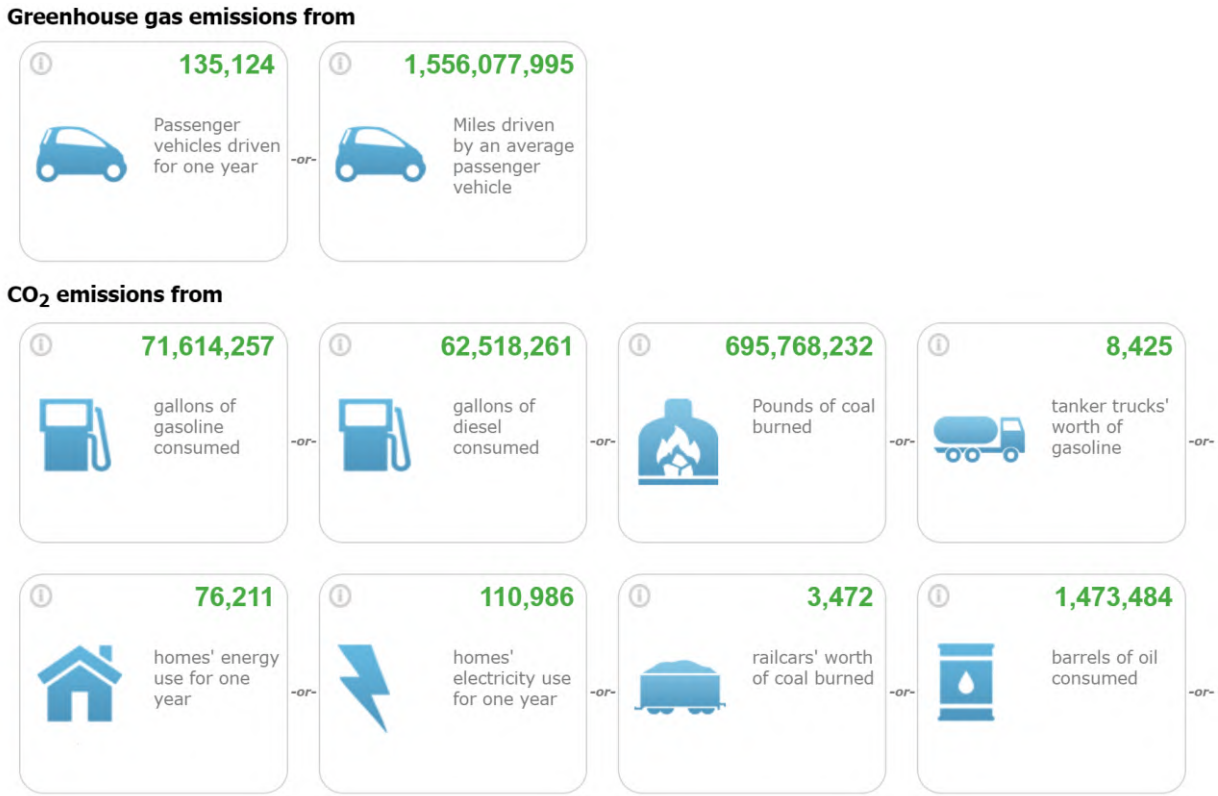
Acronyms and Abbreviations

Applicant	Obsidian Solar Center LLC
ASC	Application for Site Certificate
CWMA	Cooperative Weed Management Area
EFSC or the Council	Energy Facility Siting Council
Facility	Obsidian Solar Center
gen-tie	generation tie
HMP	Habitat Management Plan
MW	megawatts
OAR	Oregon Administrative Rule
ODFW	Oregon Department of Fish and Wildlife
ODOE	Oregon Department of Energy
OHW	ordinary high water
WLIP	Working Lands Improvement Program

1.0 INTRODUCTION

This draft Habitat Mitigation Plan ("HMP") describes how Obsidian Solar Center LLC ("Applicant") will mitigate unavoidable habitat impacts from the Obsidian Solar Center ("Facility") located in Lake County, Oregon. The purpose of the Facility is to generate renewable, clean energy that will replace, in part, energy currently generated by Northwest coal plants scheduled for closure. The Facility will operate about 30 percent of the time on a full-time equivalency basis. Applicant expects the Facility to produce about 900,000-megawatt (MW) hours per year of clean, renewable energy, which would reduce the carbon dioxide emissions equivalent to burning almost 3,500 railcars filled with coal each year (EPA 2018; Figure 1). Clean energy improvements of this kind are crucial for countering climate change, which in turn help conserve wildlife and their habitats on a landscape scale.

Figure 1. Greenhouse Gas and Carbon Dioxide Emissions Reduced Annually by the Proposed Facility



Source: EPA 2018

Habitat loss and degradation are among the greatest threats to many wildlife species around the world. Climate change also is an increasing threat to wildlife and their habitats, including to species of interest for the Facility. Research has indicated that elk (*Cervus canadensis*) (Wang et al. 2002; Sala 2006) and sagebrush habitat (Poore et al. 2009; Bradley 2010; Schrag et al. 2011) are negatively affected by climate change. Exhibit P, Section P.7.2, of the Application for Site Certificate (ASC) identifies several State Sensitive bird species in the

Facility's analysis area that are Climate Threatened or Climate Endangered, according to the National Audubon Society (2015). The Facility is a renewable energy project that will contribute to stemming climate change by reducing carbon dioxide emissions. Although the reduction in carbon emissions that will result from Facility operations may not completely counteract the loss or modification of habitat with the site boundary, it does provide a benefit to wildlife and their habitats.

This draft HMP outlines specific measures Applicant will undertake to satisfy the Oregon Energy Facility Siting Council (EFSC) Fish and Wildlife Habitat standard (Oregon Administrative Rule (OAR) 345-022-0060), which requires that the Facility, with mitigation, demonstrate consistency with the Oregon Department of Fish and Wildlife (ODFW) Habitat Mitigation Policy (OAR 635-415-0025). Applicant proposes three mitigation pathways including (1) ODFW Payment-to-Provide (Option 1), (2) a Third Party Fee-in-Lieu Program (Option 2), and (3) Working Lands Improvement Program (in-kind, in-proximity mitigation) (Option 3). Applicant opts to implement Option 3 as mitigation for the Facility. If Applicant sought to implement Option 1 or Option 2, or an ~~In addition, Applicant reserves the right to pursue~~ alternative mitigation pathways ~~if available~~ in the future, Applicant would seek ~~by pursuing~~ an amendment to this HMP, as provided under Section 6.0 below.

2.0 DESCRIPTION OF THE IMPACTS ADDRESSED BY THE HMP

The Facility is located entirely within the more than 1 million acre-area mapped by ODFW staff as elk winter range and a portion of the Facility is located within the area mapped by ODFW staff as mule deer (*Odocoileus hemionus*) winter range, which overlaps in its entirety with elk winter range (together, referred as "Big Game Winter Range"). ODFW staff has designated acres within Big Game Winter Range as Category 2 (essential and limited) habitat under ODFW's Fish and Wildlife Habitat Mitigation Policy (ODFW 2014, 2016a) ("ODFW Habitat Mitigation Policy"). ~~While Category 2 serves as the habitat category for the entire Facility, t~~The area within the site boundary consists primarily of sagebrush shrubland, with a mosaic of stand cover, plant heights, and levels of disturbance. ~~No acres of sagebrush shrubland habitat were field-characterized as Category 2 habitat, based on vegetation communities observed on-site.~~

Permanent habitat impacts will be associated primarily with the installation of permanent Facility structures. The solar array areas and related or supporting facilities will be fenced as required by electrical code and safety needs, and ODFW considers all areas inside the fence to be permanently disturbed. Temporary impacts are anticipated from the construction of the gen-tie transmission line (about 1.2 acres). Otherwise, all construction-related activities will occur within the area designated for the Facility's permanent footprint (or the area located within the perimeter fence). Temporary impacts will be fully mitigated through successful implementation of the Revegetation Plan (ASC, Appendix P-3).

The Facility will not have impacts on Category 1 habitat. The Facility will have some temporary and permanent impacts on Category 6 habitat, which do not require compensatory

mitigation.[1] For the remaining habitat types, permanent impacts must be mitigated at Category 2 under the ODFW Habitat Mitigation Policy because the impacts area is mapped Big Game Winter Range. Habitat values for Big Game Winter Range can include thermal cover, security from predation and harassment, quality forage, and limited disturbance. The area in the Facility site boundary is primarily sagebrush shrubland, and given the habitat characteristics, its primary habitat value for big game is forage and limited thermal cover.

Table 1: Acres of Temporary and Permanent Impact to Habitat within the Site Boundary

Habitat Category ~~based on Field Habitat Assessment~~	Habitat Type	Temporary Impact	Permanent Impact	Total
ODFW Designated Category 2 Habitat				
2~~3~~	Sagebrush Shrubland	0.00	3,419.21	**3,419.21**
2~~3~~	Playa OHW – Not Wetlands	0.00	16.91	**16.91**
2~~4~~	Sand Dune	0.03	108.78	**108.81**
2~~4~~	Non-sagebrush Shrubland	0.15	0.00	**0.15**
2~~5~~	Non-native Forb	0.05	42.77	**42.82**
Total Category 2 Habitat Impacts to be Mitigated		**0.23**	**3,587.67**	**3,587.90**
6	Agricultural Lands	0.56	1.00	**1.56**
6	Developed	0.21	0.00	**0.21**
	Total Impacts	**1.20**	**3,588.47**	**3,589.67**

Key:
ODFW = Oregon Department of Fish and Wildlife; OHW = Ordinary High Water

The impact analysis presented in the ASC and mitigation outlined in this HMP represents the fully built-out scenario of 400 MW. The Facility will be built as directed by market demands and power sales. For example, if Applicant enters into two separate power purchase agreements, each for 200 MW, Applicant may construct the first 200 MW and then the second 200 MW. In that case, mitigation would follow a corresponding scope and timeline.

[1] Under the ODFW Habitat Mitigation Policy, no compensatory mitigation is required for Category 6 impacts; only minimization of impacts (OAR 635-415-0025(6)).

Table 2 summarizes the habitat characteristics within the Site Boundary, as detailed in the 2018 Habitat Assessment and Biological Resources Field Report (ASC Exhibit P, Appendix P-1). Photo documentation of Area A habitat quality is also provided in photos 1-23b and 53-54 of ASC Exhibit P Appendix P-1, Attachment 1.

Table 2: Habitat Characteristics within Site Boundary

Habitat Category ~~**based on Field Habitat Assessment**~~	**Habitat Type**	**Native Shrub Stratum and Ground Cover**	**Native Herbaceous Stratum and Ground Cover**	**Bare Ground Cover**
ODFW Designated Category 2 Habitat				
2~~3~~	Sagebrush Shrubland	Big Sagebrush (*Artemisia tridentate)* (*15-30%)*, Green rabbitbrush (*Chrysothamnus viscidiflorus*) and Rubber rabbitbrush (*Ericameria nauseosa*) (*10-25%)*	Saltgrass (*Distichlis spicata*), Clasping pepperweed (*Lepidium perfoliatum*), and cheatgrass (*Bromus tectorum*) (≤ 25%)	40 – 60%
2~~3~~	Playa	Inclusions with Big Sagebrush (≤2%), Green rabbitbrush (≤8%), and shadscale saltbrush (*Atriplex confertifolia*) (≤15%)	Usually devoid; or small areas of Saltgrass (*Distichlis spicata*) (≤25%)	≥90%
2~~4~~	Sand Dune	Big sagebrush and green rabbitbrush (<5%)	Saltgrass (*Distichlis spicata*) (<5%)	

3.0 MITIGATION OPTIONS

Applicant has identified three options for addressing the mitigation obligation where habitat protection and enhancement and/or commensurate funding are feasible and consistent with the EFSC Fish and Wildlife Standard. Based on the information provided on the record of the ASC, Applicant currently may only utilize Option 3, unless ODFW adopts appropriate regulations to support Option 1 ~~or~~ and Applicant proposes an HMP amendment to utilize Option 1 or Option 2 that EFSC ~~is~~ approves~~d~~. If other mitigation options become available or are identified, Applicant reserves the right to pursue alternative mitigation pathways by pursuing an amendment to this HMP, as provided under Section 6~~7~~.0 below.

3.1 Option 1: ODFW Payment-to-Provide

Applicant understands that ODFW is considering a payment-to-provide program that could be used to mitigate habitat impacts related to energy facilities. Applicant recognizes that

Option 1 is not available at the time of ASC review but Applicant reserves the right to use Option 1 through an HMP Amendment should it be an available ODFW program in the future. Applicant, along with other certificate holders and applicants have encouraged ODFW to adopt such a program that could be used to mitigate habitat impacts related to renewable energy projects. Such a program would help further landscape-scale mitigation projects and create greater benefits for rangeland habitat, including Big Game Winter Range habitat.

3.2 Option 2: Third Party Fee-in-Lieu Program

Under this option, Applicant would partner with EFM, Inc., an affiliate of EcoTrust. Applicant and EFM would present to Oregon Department of Energy (ODOE) and ODFW a mitigation plan designed to protect and restore habitat within the Big Game Winter Range on a portion of the about 22,000 contiguous acres west of Fort Rock currently owned and being managed by EFM, including for the benefit of mule deer. The mitigation measures that would be employed on this land are different from those outlined under Option 3 given the enhancement opportunities. Applicant presents Option 2 for discussion. Applicant may not implement Option 2 without an HMP amendment as discussed above.

3.3 Option 3: Working Lands Improvement Program (in-kind, in-proximity)

Option 3 involves habitat protection and enhancement measures on lands proximate to the Facility. Specifically, Applicant would secure land in proximity to the Facility and implement a Working Lands Improvement Program (WLIP). The WLIP is twofold: it ensures that (1) there is no net loss in quantity or quality of habitat for the life of the Facility, and (2) there is a net benefit of habitat quality for the life of the Facility. Applicant will carry out the WLIP on suitable land located two to 20 miles from the Facility and within the ODFW-mapped Big Game Winter Range. These sites are considered "in-proximity" to the Facility because the identified acres are within the home range of elk and mule deer that may also use the land within the Facility site boundary.

The WLIP is a habitat protection program and a western juniper (*Juniperus occidentalis)* treatment and management program on working rangeland. The juniper program includes juniper removal and thinning, which is consistent with the Oregon Conservation Strategy's recommended approaches for conservation of sagebrush habitats. The treatment includes controlling encroaching junipers by chipping or cutting for firewood, while maintaining pre-settlement juniper stands and juniper trees with old-age characteristics, which are important nesting habitat for birds and other wildlife (ODFW 2016b). Removal of juniper can, over time, result in redistribution of water budget components in the rangeland due to lack of tree canopy interception, in turn influencing soil moisture and vegetation. In the ODFW-mapped Big Game Winter Range, juniper removal can improve the quality and quantity of sagebrush shrubland forage while preserving effective cover habitat (such as large sagebrush and old age juniper).

Working Lands Improvement Program Agreement ~~Easements~~

Applicant will enter into enforceable and recordable Working Lands Improvement Program (WLIP) Agreements ~~working land leases~~ with the underlying property owners for land

enrolled in Applicant's WLIP. A copy ~~template~~ of the WLIP Agreement ~~working lands lease~~ is included as Attachment 1. The WLIP Agreement ~~working lands lease~~ is a legally binding agreement, authorizing Applicant to implement the WLIP consistent with this HMP and obligating the property owner to manage and operate the land consistent with the goals of the WLIP. The term of the WLIP Agreement ~~working lands lease~~ is for the life of the Facility.[2] The terms of the WLIP Agreements ~~working lands leases will~~ provide for mitigation to achieve a no net loss of habitat quality or quantity. The implementation of the juniper treatment and management program on lands subject to WLIP Agreements ~~working lands leases will~~ achieve mitigation results in a net benefit of habitat quality. Applicant will provide copies of the executed WLIP Agreements ~~working lands leases~~ to ODOE prior to construction of the Facility.

WLIP Sites

Applicant performed a juniper phase desktop analysis of about 22,722 acres of land in Big Game Winter Range near the Facility site. The desktop analysis identified juniper woodland succession phases (Phase 1, Phase 2, Phase 3) and provided mapping of the phases as well as areas unsuitable for mitigation (*e.g.*, lava beds or quarries).[3] See Attachment 2. From this information, Applicant identified two property owners with large tracts of land for participation in the WLIP: the Morrison Ranch at about 1,870 acres and the Nine Peaks Ranch at about 4,500 acres, totaling about 6,370 acres.[4] Applicant conducted a preliminary desktop

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[2] "For the life of the Facility" is defined at the point when EFSC terminates the site certificate pursuant to OAR 345-027-0010. Before EFSC terminates a site certificate, the certificate holder must apply to EFSC to terminate the site certificate and provide EFSC with a proposed retirement plan consistent with OAR 345-027-0110(5), which requires, among other things, the information about how certificate holder will address impacts to wildlife and the environment during retirement. Before certificate holder may take action, EFSC must review the proposed final retirement plan, considered comments from the public and reviewing agencies, approved the proposed final requirement plan, and issued an order authorizing the retirement according to the approved final retirement plan, as provided for in OAR 345-027-0010. The approved final retirement plan will require certificate holder to restore the site and ODFW may comment on the retirement plan to ensure that the Facility continues to meet the ODFW Mitigation Policy "for the life of the Facility." EFSC may not terminate the site certificate until EFSC finds that certificate holder has completed retirement according to EFSC order authorizing retirement. See OAR 345-027-0110(8).

[3] The desktop analysis was conducted according to the protocols in the *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Circular 1321*, Miller et al. (2007).

[4] The GIS data show the Morrison Ranch and Nine Peaks Ranch mitigation area acreage as slightly larger than the tax lot acres. The GIS data show the Nine Acres Ranch mitigation area

assessment of habitat types and categories on the about 6,370 acres to confirm that the habitat is of similar structure and function as the habitat within the Facility site boundary. See Attachment 3 for the desktop habitat mapping.

The Morrison Ranch mitigation area is located, at its closest point, about 2 miles north of the Facility site boundary. This mitigation area is within the ODFW-mapped Big Game Winter Range and has about 970 acres of sagebrush shrubland and 960 acres of juniper woodland. The sagebrush shrubland within this mitigation area has similar habitat structure and function to the sagebrush shrubland within the Facility site boundary. Roughly, half of the juniper woodlands in the Morrison Ranch mitigation area are Phase 2 succession and likely support an understory with levels of sagebrush and perennial bunchgrasses that are suitable for restoration or conversion to sagebrush shrubland. The Phase 3 succession areas, which is also about half of the juniper woodland habitat in this mitigation area, may also exhibit restoration potential. The Morrison Ranch mitigation area also provides primary habitat values for big game, such as forage and thermal cover. Therefore, this land represents in-kind habitat for purposes of meeting Applicant's Category 2 habitat mitigation obligations.

The Nine Peaks Ranch mitigation area is located, at its closest point, about 7 miles north of the Facility site boundary. This mitigation area is within the ODFW-mapped Big Game Winter Range and has about 4,225 of sagebrush shrubland and 330 acres of juniper woodland. Sagebrush shrubland at Nine Peaks Ranch would be similar in structure and function as the sagebrush shrubland within the Facility site boundary; however, almost 85 percent of sagebrush shrubland in this mitigation area exhibits Phase 1 juniper encroachment. Phase 1 encroachment areas are in danger, long term, of further juniper succession, and would be great candidates for juniper restoration. The Nine Peaks Ranch mitigation area also provides primary habitat values for big game, such as forage and thermal cover. Therefore, this land represents in-kind habitat for purposes of meeting Applicant's Category 2 habitat mitigation obligations.

~~Prior to construction of the Facility~~In addition, Applicant ~~will~~ conducted field-based habitat mapping of the WLIP sites, based on a protocol approved by ODOE, in consultation with ODFW (consistent with the field-based habitat mapping performed for the field surveys conducted as a part of Exhibit P). ~~Applicant will provide t~~The resulting written report of a survey and mapping ~~to ODOE and ODFW~~ attached as Attachment 4 and provided to ODFW on or about May 22, 2020, demonstrate ~~to verify~~ that selected mitigation acres within the Morrison Ranch and the Nine Peaks Ranch are "in-kind" habitat to meet the Facility's mitigation obligations under this HMP.

Once ODOE, in consultation with ODFW, ~~has concurred~~ concurs with Applicant's field verifications, Applicant will execute WLIP Agreements ~~working lands leases~~ substantially in the form attached as Attachment 1 with the Morrison Ranch and/or the Nine Peaks Ranch.

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at about 4,595 acres and the Morrison Ranch mitigation area at about 1,939 acres, rather than 4,500 and 1,870 acres, respectively.

Land under control ~~lease~~ will total 1.2~~1~~ acres for every 1 acre of habitat impacted by the Facility components.

Implementation of the WLIP for Habitat Enhancement

Applicant will implement the WLIP across acreage totaling 1.2 acres for every 1 acre of habitat permanently impacted by the Facility components based on final Facility design. For example, if the final Facility footprint is 3,588 acres, Applicant will protect 4.306 acres of habitat from development and conduct the habitat enhancement measures across the 4,306 acres, as described below. ~~The WLIP includes the following components[5]:~~

Step 1: Pre-Treatment Juniper Survey

Applicant ~~will~~ conducted a pre-treatment survey to determine the appropriate j~~J~~uniper t~~T~~reatment areas ~~Unit, facilitate preparation of the applicable Juniper Treatment Plan for that Unit,~~ and record pre-treatment conditions (the "Pre-Treatment Survey"). The Pre-Treatment survey ~~will also~~ informed the Juniper Treatment Plans. ~~The Pre-Treatment Survey may occur as part of, or concurrently with, the pre-construction field-based habitat assessment of the WLIP sites (as described above).~~ The Pre-Treatment Survey ~~will~~ was ~~be~~ conducted in accordance with a protocol, ~~to be~~ submitted and approved by ODFW, based on the methods included in the *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Survey Circular 1321* (Miller et al, 2007). ~~The Pre-Treatment Survey will document dominant plant species within each habitat type, including general habitat conditions, such as tree and shrub heights and cover (including presence of pre-settlement junipers), weed species and coverage, and level of disturbance. Applicant shall provide the results of the Pre-Treatment Survey to ODOE and ODFW.~~

~~Applicant will use the desktop analysis and field-based habitat/weed surveys, in consultation with its qualified consultants, to identify Juniper Treatment Units within the WLIP sites. The Juniper Treatment Units may vary in size depending on natural landscape divisions, qualities, prior uses, etc. and the treatment schedule for different Juniper Treatment Units may vary.[6]~~

Step 2: Develop Juniper Treatment Plan

~~Prior to construction of the Facility, following completion of the Pre-Treatment Habitat/Weed Surveys,~~ Applicant ~~will~~ has developed and submitted for review and approval to ODOE, in consultation with ODFW, ~~a~~ juniper treatment ~~plan or~~ plans ~~depending on the areas selected~~

~~[6] As stated in the ASC, Applicant will develop the Facility based on market demands and other factors. This means that construction may occur in steps or on a rolling basis. Mitigation for each step of construction or implementation of rolling mitigation would correspond to the rolling construction.~~

for treatment within the WLIP sites.~~site-specific Juniper Treatment Plan(s). A Juniper Treatment Plan, A~~~~at a minimum, t~~The plans ~~will~~ include the following components:

- Habitat maps identifying the boundary of proposed ~~Juniper Treatment Unit within WLIP site and~~ treatment areas.

- A description and figures ~~table~~ identifying approximate acres of treatment areas by treatment type~~application per treatment plan for the Juniper Treatment Unit (*e.g.*, xx acres for thinning, xx acres for juniper removal, xx acres for protection of juniper stands)~~.

- Best management practices to minimize the risk of noxious weed introduction into juniper treatment areas including equipment wash out station, reseeding of burned slash treatment piles with a grass/legume mix (within 30 days of the fire), and monitoring burned areas for noxious weeds (annually for three years following reseeding).

- A protocol establishing methods for documentation of pre- and post-treatment conditions such as through photo documentation; and, field based methods including walking a representative sample of 100-meter random transects to assess soil disturbance and vegetation conditions (plant cover, native herbaceous cover, non-native cover).

- Recommendations for post-treatment monitoring, weed treatment, and juniper re-treatment.

~~A Juniper Treatment Plan may correspond to one or more designated mitigation units within the WLIP sites. Mitigation work must commence within the same season or year of the correlative Facility construction commencement, based on final Facility design and construction schedule at that time. Following construction completion, Applicant may adjust the mitigation obligation (site size, extent of juniper treatment) if changes in final Facility design during construction occur that reduce the mitigation obligation.~~

Step 3: Juniper Treatment

~~Applicant~~ Certificate holder will hire one or more contractors (locally, to the extent possible) to implement the Juniper Treatment Plan(s) across the WLIP sites. Depending on the local site conditions and the capabilities of the contractor(s), felled juniper may be burned on site or hauled away. If slash burning is to occur, contractor will obtain necessary burn permits and will coordinate with landowners, as applicable. Juniper may also be sorted and decked, delimbed, and any commercial product taken off site. ~~Juniper Treatment Plans will emphasize retaining pre-settlement juniper (or late successional junipers) and removing young juniper encroaching into pre-settlement juniper stands as well as other young juniper within the treatment area. The methods for juniper removal will vary depending in local site conditions. One method would be to hand cut and hand pile the trees. Another would be to pull the mid-sized juniper with a rubber tire tractor or small excavator and hand cut the large and very small post-settlement juniper; all juniper would be mechanically piled~~. In

implementing t~~T~~he Juniper Treatment Plans, Certificate holder will direct the cutting contractor to minimize impacts to sagebrush in the understory.

Step 4: Weed Monitoring and Treatment

Applicant will engage the Lake County Cooperative Weed Management Area (Lake County CWMA) to monitor the WLIP sites for noxious weeds. Lake County CWMA will monitor noxious weeds within a treated area annually for two years ~~Juniper Treatment Unit within 12 months and again within the following 12 months~~ after initial juniper treatment and will treat weeds as needed during the monitoring. In addition, Lake County CMWA will monitor burned slash treatment pile areas annually for ~~in year~~ 3 years following reseeding and will treat weeds as needed during the monitoring. Applicant will provide copies of the annual weed monitoring and treatment reports to ODOE and ODFW. Thereafter, Lake County CWMA will monitor and treat noxious weeds in the WLIP sites as described below.

Step 5: Monitoring and Reporting

Applicant will hire a qualified contractor to conduct monitoring in the treated areas ~~of each Juniper Treatment Unit~~ and provides reports to ODOE, ODFW, and Lake County as provided for in the applicable Juniper Treatment Plans. The monitoring program will consist of monitoring for noxious weeds as well as monitoring for mitigation success.

Generally, the first post-treatment monitoring for mitigation success will occur within one year ~~begin about 24 months~~ after the initial j~~J~~uniper t~~T~~reatment is completed and continue every ~~seven~~ ten years thereafter for the life of the Facility. Polygons where no treatment is planned will be monitored when neighboring polygons with a common boundary are scheduled for treatment or monitoring. Monitoring measures to be documented include:

- Confirm ongoing compliance with WLIP ~~leases~~agreements;
- Assess changes in vegetation cover (species, structural stage, health), and progress towards meeting success criteria, including the presence or lack of noxious weeds;
- Document environmental factors such as average rainfall, average snowfall, occurrence of wildfire, etc.; and
- Assess juniper encroachment to evaluate whether retreatment may be needed, using the location points identified during the initial Juniper Treatment.

Prior to construction of the Facility, Applicant shall provide a draft report template for review and comment by ODOE, in consultation with ODFW. Based on the agency-reviewed report template, Applicant will provide ODOE and ODFW a report following each monitoring period detailing the observations and results, including the details of any noxious weed treatment and juniper retreatment.

4.0 SUCCESS CRITERIA

Given the Facility's location in ODFW-mapped Big Game Winter Range, Applicant must meet Category 2 mitigation goal of "no net loss of either habitat quantity or quality and to provide a net benefit of habitat quantity or quality." The mitigation measures presented in this draft HMP ensure that the Facility's permanent and temporary impacts will not result in a net loss of habitat quantity or quality and result in a net benefit of habitat quality. Applicant will measure success during its monitoring periods and success will be based on the following indicators:

- Increase in herbaceous cover within the WLIP treatment areas, compared to reference sites, based on soil characteristics, precipitation regimes, native plant association prior to juniper encroachment, historical fire regime, and desired future condition using *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Circular 1321*, Miller et al. (2007);

- Maintenance of ~~a specified percent~~ juniper ~~overstory~~ encroachment or overstory within the Juniper Treatment Areas (~~to~~ as ~~be~~ specified in the applicable Juniper Treatment Plan ~~after the Pre-Treatment Survey has been completed~~);

- Response of sage brush and/or bitter brush as measured by the leader growth in the cut areas within a Juniper Treatment Unit compared to areas without cutting in the Juniper Treatment Unit; and

- Successful weed control (weed monitoring and treatment) within the WLIP sites for the life of the Facility.

~~Success criteria may be further refined in the Juniper Treatment Plans depending on Applicant's juniper contractor recommendations, the Pre-Treatment Survey, and other site-specific conditions for the treatment area within the WLIP. Applicant is mitigating primarily for impacts to sagebrush shrubland, which was preliminarily identified as Category 3 habitat based on vegetative characteristics observed during field habitat assessments, but was designated as Category 2 because of the ODFW-mapped Big Game Winter Range overlay. As a result, habitat within the WLIP sites will only need to be enhanced to the extent it provides the quality of habitat impacted by the Facility.~~

5.0 PRE-CONSTRUCTION COMPLIANCE

The final HMP applies to the entirety of permanent and temporary Category 2 habitat impacts.[7] This draft HMP contains ~~numerous~~ pre-construction requirements to which Applicant must comply. As described throughout this plan, prior to construction of the Facility, Applicant shall:

- ~~Develop and submit a habitat assessment protocol for the Facility site boundary and the WLIP sites for review and approval by ODOE in consultation with ODFW;~~\

- Identify the total number of permanent and temporary habitat acres to be impacted, based on permanent facility components within the perimeter fence line and temporary impacts outside of the fence line, including any important assumptions or calculations;

- Executed WLIP Agreements~~landowner agreements~~, with an opportunity for review and concurrence by ODOE if agreements contain termination or amendment clauses;

- Finalize ~~Draft~~ Juniper Treatment Plan(s) ~~(for the Juniper Treatment Units commensurate in size to the initial construction area),~~ including maps of treatment areas; treatment plans and methods, pre- and post-documentation protocols, monitoring and reporting protocols.

6.0 AMEMDMENTS TO THE HMP

The HMP may be amended from time to time upon approval by EFSC, who may delegate its authority to review and authorize amendments to ODOE. ODOE must notify EFSC of all amendments and EFSC retains the authority to approve, reject, or modify any amendments to this HMP agreed to by ODOE.

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[7] Applicant began construction in 2019 on two solar projects located on land within the Facility site boundary under Lake County Permit No. 19-027-CUP and Lake County Permit No. 19-028-CUP. Applicant is implementing mitigation measures for each project under the respective CUP approvals. Applicant will terminate Lake County Permit No. 19-027-CUP and Lake County Permit No. 19-028-CUP once Applicant has demonstrated compliance with the Facility site certificate's pre-construction conditions of approval, at which point the solar development previously approved under the County CUPs will become subject to EFSC jurisdiction. Applicant proposes a condition of approval requiring an HMP status report to ODOE prior to construction confirming that mitigation conducted under the two county permits meets and will continue to meet the mitigation requirements under this HMP.

7.0 REFERENCES

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WORKING LANDS IMPROVEMENT AGREEMENT

This Working Lands Improvement Agreement ("Agreement") is entered into this _____day of_____, 2020, ("Effective Date"), between _____, ("Property Owner"), and Obsidian Solar Center, LLC, an Oregon limited liability company ("Obsidian").

Recitals

A. Obsidian is developing a solar photovoltaic energy facility on approximately 3,900 acres of rangeland in northern Lake County, Oregon ("Facility").

B. The Facility is subject to review and approval by the Oregon Energy Facility Siting Council ("EFSC"). As a part of the EFSC permitting process, Obsidian is required to develop a Habitat Mitigation Plan ("HMP") to mitigate for impacts to habitat, including area mapped by the Oregon Department of Fish and Wildlife ("ODFW") as big game winter range.

C. The HMP requires Obsidian to secure land in proximity to the Facility and implement the mitigation measures described in the HMP, which include a Working Lands Improvement Program ("WLIP"). The WLIP is a western juniper (*Juniperus occidentalis*) treatment and management program on working rangeland and involves juniper removal and thinning, controlling encroaching junipers by chipping or cutting for firewood, and maintaining pre-settlement juniper stands and juniper trees with old-age characteristics, which are important nesting habitat for birds and other wildlife.

D. The purpose of the WLIP is to ensure that there is no net loss in quantity or quality of habitat for the life of the Facility and there is a net benefit of habitat quality for the life of the Facility.

E. This Lease facilitates Obsidian's implementation of the WLIP under the HMP and obligates Property Owner to manage and operate the Property (as defined below) consistent with the goals of the WLIP for the life of the Facility as described herein.

NOW THEREFORE, for good and adequate consideration, the parties agree as follows:

1. **Description of Property**. Property Owner grants Obsidian the non-exclusive right to use approximately 1,870 acres of working rangeland in north Lake County, as further described in Exhibit A and shown in Exhibit B ("Property"), for the purposes described herein and subject to the restrictive covenants described herein. Property Owner grants Obsidian a non-exclusive license of ingress and egress to and from the Property over the routes and easements historically and customarily used or hereafter constructed or useful to access the Property. The Agreement excludes oil and gas rights and the improvements consisting of barns, shops, residence, all of which are reserved for the continued use of Property Owner and excluded from the Property. Property Owner is responsible for maintaining all existing improvements on the Property.

2. **Term of Agreement**. The initial term of this Agreement shall be 30 years, commencing on _____ and expiring on _____ ("Initial Term"). Obsidian will have two (individually, an "Option") options to renew this Agreement for five years (individually, a "Renewal Term") at the end of the Term or Renewal Term by providing written notice to Property Owner at least 60 days prior to the then-current expiration of the Term or Renewal Term.

3. **Rent**. Obsidian agrees to pay Property Owner cash rent in the amount and on the terms set forth in Exhibit C, which shall be redacted in the recorded version of this Agreement. Rent for any partial year shall be prorated based upon the number of days in which this Agreement was effective during such year.

4. **Binding Nature of Agreement**. The terms of this Agreement shall be binding upon the heirs, executors, administrators, successors and assigns of both Property Owner and Obsidian in like manner as upon the original parties. If the Property Owner should sell or otherwise transfer title to the Property, it will do so subject to the terms and conditions of this Agreement. At any time during the Term of this Agreement or any Renewal Term should the Property be transferred, sold or conveyed, be subject to foreclosure, bankruptcy or transferred by any other means whatsoever, the Property Owner, sponsor or administrator shall immediately notify Obsidian in writing.

5. **WLIP Restrictions**. Property Owner covenants and agrees that it will not use the Property in a manner that is likely to undermine the effectiveness or is otherwise contrary to the Obsidian's habitat mitigation and enhancement activities performed on the Property pursuant to the HMP.

    a. The following activities are specifically permitted on the Property without violating the terms and conditions of this Agreement: (i) hunting, fishing, hiking, or passive recreation; (ii) fencing to prohibit entrance of livestock and trespassers; (iii) posting of signs; (iv) building or remodeling a primary residence, agricultural building, or similar structure to serve ongoing agricultural operations so long as the total such use does not exceed five (5) acres; (vi) current use of land under existing grazing management plans; and (vii) implementation of approved conservation and wildlife management plans consistent with the HMP.

    b. The following activities are specifically prohibited on the Property under this Agreement: (i) increased grazing above levels approved under existing grazing management plans unless otherwise approved in writing by ODFW; (ii) all nonagricultural uses unless otherwise specified in Section 5(a) above; (iii) grading, mowing, blading, or expansion of impervious surfaces or access road networks; and (iv) divisions of the Property.

c. Activities not specifically permitted or specifically prohibited may be allowed subject to consultation with and prior approval of the Obsidian and ODFW.

6. **Alterations by Obsidian**. Property Owner acknowledges that the Obsidian intends to use the Property to implement the WLIP and meet its corresponding mitigation obligations described in the HMP. Except as set forth in a written juniper treatment plan or weed control plan developed pursuant to the HMP and provided to Property Owner, Obsidian will make no improvements or alterations on the Property of any kind without first obtaining Property Owner's written consent,. Any alteration will be made in a good and workman-like manner, and in compliance with applicable laws and building codes.

7. **Coordination with Property Owner**. To implement the WLIP, Obsidian will hire one or more contractors (locally, to the extent possible). Obsidian will provide Property Owner written notice of the name and contact information of any contractor engaged by Obsidian to perform work on the Property. Obsidian will provide written notice at least five (5) days prior to the first day of the scheduled work. Such work may include but is not limited to juniper treatment, juniper removal, monitoring, and weed treatment. Property Owner will coordinate with Obsidian if undertaking any activities described in Section 5 above by providing reasonable written notice to ensure that such activities will be performed consistent with the mitigation goals of the HMP. Property Owner also grants limited access rights to ODFW and the Oregon Department of Energy ("ODOE") to access the Property upon prior reasonable written notice to Property Owner and Obsidian for the purposes of inspecting the mitigation work.

8. **Juniper Disposal Methods**. Depending on the local site conditions, the capabilities of the contractor(s), and Property Owner's preferences, cut juniper may be burned onsite, hauled offsite, or some combination of disposal methods may be used. Obsidian will coordinate the selection of the disposal method for cut juniper and slash with Property Owner. If the disposal method is burning, Obsidian or its contractor will obtain all necessary burn permits and coordinate the burn date with Property Owner. To the extent practicable, commercially valuable juniper will be salvaged and hauled offsite and any proceeds will first go to offset rent payments within the last 12 months and then go to the Property Owner.

9. **No Encumbrances or Liens**. Obsidian shall not cause, suffer or permit to be filed against all or any portion of the Property any mechanic's or similar lien for any work done or materials supplied to the Property by or at the request of Obsidian or its authorized agent ("Lien"). If any Lien shall be filed against all or any portion of the Property (i) Obsidian shall give notice thereof to Property Owner within five business days after the date on which Obsidian first becomes aware of such Lien, and (ii) within 30 days after first becoming aware of such filing and prior to any foreclosure, Obsidian, at its sole cost and expense, shall cause the Lien to be discharged of record or bonded over, failing which Property Owner shall have the right, but shall not be obligated, to discharge the Lien without investigating the validity or

amount thereof. Obsidian shall reimburse Property Owner on demand for any amounts so paid or incurred by Property Owner, including reasonable expenses and attorneys' fees. .

10. **Taxes**. Property Owner shall pay when due all real property taxes on the Property and the improvements located on the Property**.**

11. **Insurance by Obsidian**. From and after the Effective Date, Obsidian, at its sole cost and expense, shall obtain and maintain the following insurance during the Term:

    a. Commercial general public liability insurance against any and all claims arising out of liability for personal injury, including illness and death, with limits of not less than $2,000,000 per occurrence, and property damage in and about the Property and otherwise resulting from any acts or operations of Obsidian, with a combined single limit of $2,000,000 per occurrence;

    b. Property insurance coverage Obsidian's personal property protecting against risk of physical loss or damage in an amount not less than the actual replacement cost thereof; and

    c. Workers' compensation and employer's liability insurance as required by applicable law.

    Obsidian is not responsible for paying or maintaining fire and property damage insurance. Any additional insurance coverage for the Property shall be the responsibility of the Property Owner.

12. **Release and Waiver of Subrogation**. The parties hereto release each other, and their respective agents and employees, from any liability for injury to any person or damage to property that is caused by or results from any risk insured against under the insurance policies required to be carried by either of the parties, which policies shall contain a waiver of subrogation by the insurer that provides that the insurer waives all right of recovery by way of subrogation against the other party and its agents and employees in connection with any injury or damage covered by such policy.

13. **Indemnification**. Each party hereby agrees to indemnify, defend and hold harmless the other party and their respective directors, employees and agents from and against any and all third party claims, actions, demands, liabilities, expenses and/or losses, including reasonable legal expenses and reasonable attorneys' fees ("Losses") the extent such Losses result from any, but except to the extent caused by the negligence or misconduct of the other party: (a) breach of warranty by the indemnifying party contained in this Agreement; (b) breach of this Agreement by the indemnifying party; or (c) negligence or willful misconduct of the indemnifying party or their respective directors, employees, and agents in the performance of this Agreement.

14. **Hazardous Materials.** Neither Obsidian nor any of its employees or contractors (each a "Obsidian Party") shall use, store, deposit, handle, transport, release, or dispose of Hazardous Materials in, on or about the Property in violation of any federal, state or municipal law, decision, statute, rule, ordinance or regulation currently in existence or hereafter enacted or rendered. Obsidian shall indemnify, defend and hold Property Owner harmless from and against any claims, penalties, fines, liabilities, settlements or damages (but excluding consequential damages) arising out of: (1) the release, use, storage, treatment, transportation, transfer, handling or disposal of any Hazardous Materials , on, over, under, from or affecting the Property (a "Release") caused by Obsidian or a Obsidian Party, or (2) any violation of or liability pursuant to environmental laws which is based upon or in any way related to such Release, in each case except (a) those matters to the extent resulting from the negligence or misconduct of Property Owner, its successors and assigns, and their respective directors, officers, employees, contractors and agents, (b) matters that result from Pre-Existing Environmental Conditions unless and only to the extent exacerbated by the gross negligence or willful misconduct of Obsidian or any Obsidian Party, or (c) matters that result from the actions of third parties, including but not limited to the migration of Hazardous Materials to the Property from an offsite source. The indemnity provided in this Section shall survive the termination of this Agreement.

    As used herein, the term "Hazardous Materials" shall mean and be defined as any and all toxic or hazardous substances, chemicals, materials or pollutants, of any kind or nature, which are regulated, governed, restricted or prohibited by any federal, state or local law, decision, statute, rule, or ordinance currently in existence or hereafter enacted or rendered, and shall include (without limitation), all oil, gasoline and petroleum based substances asbestos, toxic molds and per- and polyfluoroalkyl substances ("PFAS"). As used herein, the term "Pre-Existing Environmental Condition" means presence of: (i) Hazardous Materials in soil, groundwater, soil vapor, ambient air or surface water on or about the Property in amounts, concentrations or levels that meet or exceed Environmental Requirements, including cleanup or other standards applicable to Hazardous Materials or which otherwise require remedial action under Environmental Requirements, which first existed or first occurred prior to the Effective Date; or (ii) any other environmental condition which first existed or first occurred prior to the Effective Date. "Environmental Requirements", as used herein, shall mean all applicable federal, state, and local government laws (including common law), rules, regulations, statutes, codes, ordinances, directives, guidance documents, cleanup or other standards, and any other governmental requirements or standards which pertain to, regulate, or impose liability or standards of conduct concerning the use, storage, human exposure to, handling, transportation, release, cleanup, remediation or disposal of Hazardous Materials.

15. **Subordination and Non-Disturbance**. If any mortgage, deed of trust, deed to secure debt or similar instrument encumbers Property Owner's interest in the Property ("Fee Mortgage") and is senior in priority to the Agreement, Property Owner agrees to obtain a nondisturbance agreement in form reasonably satisfactory to Obsidian pursuant to which holder of such Fee

Mortgage agrees not to disturb the possession of the Obsidian and its successors and assigns so long as Obsidian and its successors and assigns comply with this Agreement. In the event of foreclosure of any Fee Mortgage by voluntary agreement or otherwise, or the commencement of any judicial action seeking such foreclosure, Obsidian will become the Obsidian of and recognize such lender or purchaser in foreclosure as Obsidian's landlord under this Agreement without change in the provisions of this Agreement. Upon request by such successor in interest, Obsidian will execute and deliver an instrument confirming such attornment, which will recognize this Agreement and the rights of Obsidian set forth herein and shall provide that such successor in interest will not disturb Obsidian in its use of the Property in accordance with this Agreement unless Obsidian fails to comply with this Agreement.

16. **Compliance with Laws**. Obsidian shall comply with all applicable laws concerning Obsidian's specific use, occupancy, and activities in the Property. Property Owner will give prompt notice to Obsidian of any notice it receives of the violation of any law or requirement of any public authority with respect to the Property or the use or occupancy thereof.

17. **Quiet Enjoyment**. Property Owner covenants, represents and warrants to Obsidian that (i) Property Owner is the owner of the Property free and clear of (a) any prior encumbrance inconsistent with Obsidian's rights under this Agreement and (b) any prior mortgage or lien, (ii) Property Owner has the right to lease the Property, (iii) Property Owner shall not cause or allow any activity or use of the Property or Property Owner's adjacent property to interfere with Obsidian's use and enjoyment of the Property or the rights granted to Obsidian under this Agreement, (iv) nothing contained in any easement, covenants, conditions, declarations, limitations, or restrictions now or hereafter of record which are (or shall be) applicable to the Property shall prevent Obsidian from operating in the Property or require Obsidian to make any alterations, repairs modification or installments to the Property or require Obsidian to make any payment or perform any obligations not expressly required by Obsidian under this Agreement, and (v) Obsidian shall be entitled to quiet enjoyment of the Property and to the rights and privileges of Obsidian under this Agreement during the Term.

18. **Notices**. Any notice required or permitted to be given under this Agreement shall be deemed given if delivered personally to an officer or general partner of the party to be notified or sent by (a) United States registered or certified mail, postage prepaid, return receipt requested, or (b) overnight courier service and addressed as follows:

If to Property Owner: _____
_____
_____

If to Obsidian: Obsidian Solar Center, LLC
Attn: David Brown
5 Centerpointe Dr #350

Lake Oswego, OR 97035

With a copy to: Davis Wright Tremaine LLP
Attn: Elaine Albrich
1300 SW Fifth Avenue, Suite 2400
Portland, OR 97201

or such other address as may be designated by either party by written notice to the other. Except as otherwise provided in this Agreement, every notice, demand, request or other communication hereunder shall be deemed to have been given or served upon actual receipt thereof. Accordingly, a notice shall not be effective until actually received. Notwithstanding the foregoing, any notice mailed to the last designated address of any person or party to which a notice may be or is required to be delivered pursuant to this Agreement shall not be deemed ineffective if actual delivery cannot be made due to a change of address of the party or party to which the notice is directed or the failure or refusal of such person or party to accept delivery of the notice.

19. **No Partnership of Joint Venture**. Property Owner shall not, by virtue of this Agreement, in any way or for any purpose, be deemed to be a partner of Obsidian in the conduct of Obsidian's business upon within or from the Property or otherwise, or a joint venturer or a member of a joint enterprise with Obsidian.

20. **Entire Agreement**. This Agreement contains the entire agreement between the parties and, except as otherwise provided herein, can only be changed, modified, amended or terminated by an instrument in writing executed by the parties.

21. **Severability**. If any provision of this Agreement shall be deemed to be invalid, it shall be considered deleted therefrom and shall not invalidate the remaining provisions of this Agreement.

22. **Applicable Law**. This Agreement shall be governed by, and construed in accordance with the laws of the State of Oregon.

23. **Recordation of Memorandum of Agreement**. On the Effective Date, Property Owner will execute, acknowledge, and deliver to Obsidian a memorandum substantially similar to the memorandum attached hereto as Exhibit D, documenting the existence of this Agreement.

24. **Counterparts**. This Agreement may be executed in counterparts by the parties hereto and each shall be considered an original, but all such counterparts shall be construed together and constitute one Agreement between the parties hereto.

[signatures on next page]

IN WITNESS WHEREOF, the parties hereunto affixed their signatures the day and year first above written.

Property Owner:	Obsidian:
	OBSIDIAN SOLAR CENTER, LLC
By:_____	By:_____
Name: _____	Name: _____
Its: _____	Its: _____

Exhibit A

Legal Description of Property

Exhibit B

Depiction of Property

Exhibit C

Rent

EXHIBIT E

Memorandum of Agreement

This document was prepared by and

after recording should be returned to:

Davis Wright Tremaine LLP

1300 SW Fifth Avenue, Suite 2400

Portland, Oregon 97201

Attn: Elaine Albrich

_____

(space above reserved for recorder's use)

Memorandum of Agreement

This Memorandum of Agreement ("Memorandum") is made as of _____, 2__, by and among _____ ("Property Owner"), and **OBSIDIAN SOLAR CENTER, LLC,** an Oregon limited liability company ("Obsidian").

1. **Premises**. Property Owner leases to Obsidian that certain real property located at _____, Oregon and legally described and shown on the attached Exhibit A ("Premises") upon the terms and conditions of that certain Working Lands Improvement Agreement between the parties dated _____, 20__ ("Agreement"), which is incorporated herein by reference.

2. **Term**. The initial term of the Agreement will expire on _____. Obsidian has the option to extend the term for two addition five-year periods, according to the conditions set forth in the Agreement.

3. **Purpose of Memorandum**. This Memorandum is prepared for the purpose of recordation to give notice of the Agreement. This Memorandum shall not constitute an amendment or modification of the Agreement, and in the event of any conflict between the terms of this Memorandum and the Agreement, the terms of the Agreement shall control.

IN WITNESS WHEREOF, the parties hereto have caused this Memorandum to be duly executed as of the Effective Date.

PROPERTY OWNER:

By:_____

Name:

Its:

OBSIDIAN:

OBSIDIAN SOLAR CENTER, LLC,

an Oregon limited liability company

By:_____

Name: _____

Its: _____

STATE OF OREGON)

) ss.

County of _____)

This instrument was acknowledged before me on this ____day of _____, 20__, by _____ in his/her capacity as _____ of Obsidian Solar Center LLC and acknowledged that he/she is authorized on behalf of the company to execute the same.

_____

Notary Public for Oregon

My Commission Expires:_____

STATE OF OREGON)

) ss.

County of _____)

This instrument was acknowledged before me on this ____day of _____, 20__, by _____ in his/her capacity as _____ of _____ and acknowledged that he/she is authorized on behalf of the company to execute the same.

_____

Notary Public for Oregon

My Commission Expires:_____

EXHIBIT A

LEGAL DESCRIPTION OF PREMISES

Attachment 3
Supplemental Evidence for Success of Juniper Removal

Boyce, M.S., M.G. Turner, J. Fryxell, P. Turchin. 2003. Scale and heterogeneity in habitat selection by elk in Yellowstone National Park. EcoScience. 10(4), 421-431.

Coe, P.K., D.A. Clark, R.M. Nelson, S.C. Gregory, J.B. Cupples, M.J. Hedrick, B.K. Johnson, D.H. Jackson. 2018. Multiscale models of habitat use by mule deer in winter. J. Wildl. Manage. 10.1002/jwmg.21484.

Davies, K.W., C.S. Boyd, J.L. Beck, J.D. Bates, T.J. Svejcar, M.A. Gregg. 2011. Saving the sagebrush sea: strategies to conserve and restore big sagebrush plan communities. Biol. Conserv. 144, 2573-2584.

Leckenby, D. A., and A. W. Adams. 1986. A weather severity index on a mule deer winter range. Journal of Range Management 39:244–248.

Miller, R.F., J.R. Rose. 1995. Historic expansion of *Juniperus occidentalis* in southeast Oregon. Great Basin Nat. 55, 37-45.

Miller, R.F., J.D. Bates, T.J. Svejcar, F.B. Pierson, L.E. Eddleman. 2005. Biology, ecology and management of western juniper. OR State Univ. Agricultural Experiment Station Tech. Bull. 152.

Vaitkus, M.S., L.E. Eddleman. 1987. Composition and productivity of western juniper understory and its response to canopy removal. In: Everett, R.L. (Ed.) Proceedings Pinyon-Juniper Conference. Gen. Techn. Rep. INT-215, USDA-FS, Intermountain Forest and Range Experiment Station. Ogden, UT. pp 456-460.

Pre-Treatment Juniper Field Survey Report

Prepared For:

Obsidian Solar Center LLC

5 Center Point Drive, Suite 250

Lake Oswego, OR, 97035

Prepared By:

Fosters Natural Resource Contracting

16981 Highway 395, Lakeview, OR, 97630.

541-219-0252

fostersnrc@gmail.com.

Introduction

Obsidian Solar Center LLC (Obsidian) is applying for a site certificate from the Oregon Energy Facilities Siting Council (EFSC) to build and operate the Obsidian Solar Facility in the Fort Rock Valley of Lake County, Oregon (Facility). A condition of the site certificate will require Obsidian to mitigate for the Facility's impacts to Category 2 big game winter range habitat. Obsidian has developed a Habitat Mitigation Plan (HMP). The HMP proposes to establish a Working Lands Improvement Program (WLIP) on portions of two properties, totaling 6,534 acres in the Fort Rock Valley (HMP Attachment 3). The total acreage enrolled in the WLIP will depend on the permanent footprint from the Facility's final design. The WLIP is two-fold: it involves habitat protection under a WLIP landowner agreement, and big game winter habitat enhancement using a juniper treatment program. The HMP identifies 5 steps to implement the juniper treatment and management program (HMP Section 3.3, page 8). Steps 1 and 2 involves completing a pre-treatment juniper (*Juniperus occidentalis*) field survey and developing a juniper treatment plan for the two properties. The purpose of this document is to present results of the juniper field survey (Step 1).

The goal of the WLIP is to provide mitigation by maintaining and improving big game winter habitat on the mitigation properties. Winter range will be maintained by establishing a WLIP agreement with the landowners. Big game winter range will be improved by providing a mosaic of vegetation associations designed to provide big game cover and forage areas across the properties. Juniper encroachment into shrub steppe habitats results in reduced forage quality and quantity due its ability to out compete shrubs and bunchgrass (Vaitkas and Eddleman 1987, Miller and Rose 1999, Miller et al. 2005, Davies et al. 2011). Forest vegetation associations are an important habitat component for wintering big game as they provide both thermal and hiding cover (Leckenby and Adams 1986, Boyce et al. 2003, Coe et al. 2018). Juniper woodlands are the primary forest habitat available during winter in the Fort Rock Valley (Coe et al. 2018). Therefore, actions under the HMP are not designed to just cut juniper, but are intended to provide quality winter habitat on the properties.

Pre-Treatment Juniper Survey

Juniper surveys were completed during the first 2 weeks of April and the second week of May, 2020 using the Obsidian habitat assessment protocol (Appendix 1) approved by Oregon Department of Energy (ODOE) in consultation with Oregon Department of Fish and Wildlife (ODFW). As directed in the habitat assessment protocol field surveys for noxious weeds were conducted while completing the juniper surveys.

Nine Peaks Ranch

Field surveys were conducted on approximately 4,595 acres in a single parcel of the Nine Peaks Ranch. Results of the juniper survey are presented in Tables 1 and 2, and Figures 1, 1a and 1b. Juniper densities shown in Table 1 were measured using one or more 100 yard X 20 yard (0.4 acre) transects per vegetation association polygon.

Soils are generally sandy to ashy loams with varying amounts of rock. Rock ranges from none in areas with gentle slopes to ridges with significant cobble or large stone. Basalt outcrops and degraded lava flows are common. Average annual precipitation is 12 inches, most of which falls as snow in the winter. The Nine Peaks parcel lies within the Paulina wildlife management unit (WMU) on big game winter range designated in the Lake County Comprehensive Land Use Plan. In addition to its importance as winter range, the Nine Peaks property is located between the Devils Garden and East Lava Field and is a significant migration corridor for mule deer moving to and from other winter areas in the Paulina and Fort Rock WMUs (Coe et. al, 2018).

The property has been managed as a working livestock operation since at least the early 1900's. Valley bottoms with sandy or ashy loam soils were converted to rye (*Secale cereale*) hay fields, then in the 1970's or 1980's those fields were seeded to crested wheatgrass (*Agropyron cristatum*). Gray rabbitbrush (*Ericameria nauseosus*) has established in the crested wheatgrass seedings. Cattle are grazed using a rest rotation system.

Past management actions or wildfire have resulted in most of the juniper stands on sandy to ashy loam soils being in phase 1 or early phase 2 condition. Pre-settlement or mixed pre-settlement/late phase 2-phase 3 stands are common and occur on cobble to rocky soils, degraded lava eruptions or rock outcrops.

Elevations range from 5200 feet on the north end of the property to 4500 feet on the south, with the majority of the property being below 4900 feet. Areas above 5000 feet elevation are ponderosa pine (*Pinus ponderosa*) forest stands with a bitterbrush (*Purshia tridentata*)/ Idaho fescue (*Festuca idahoensis*) understory. Between 5000 and 4900 feet, ponderosa pine and juniper are codominant, shrubs are bitterbrush and mountain big sagebrush (*Artemesia tridentata vasyeana*), and Idaho fescue is the dominant grass. Below 4900 feet vegetation associations are variable with areas not converted to crested wheatgrass dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) and gray rabbitbrush with a mix of native bunchgrass including: Idaho fescue, blue bunch wheatgrass (*Pseudoroegneria spicatum)*, Thurbers needlegrass (*Achnatherum thurberianum*), Indian rice grass (*Achnatherum hymenoides*), squirrel tail grass (*Elymus elymoides*) and Sandberg's blue grass (*Poa sandbergii*).

No weed species of concern (Table 1, Attachment 2) were found on either property. Cheatgrass (*Bromus tectorum*), is widely distributed across both properties. Tumble mustard (*Sysimbrium altissimum*) and tansy mustard (*Descurania spp.*) are common in disturbed sites. Although these species are non-native and invasive, they are widely naturalized throughout North America and should not be a specific target of weed control on big game winter range.

Table 1. Nine Peaks Ranch, Fort Rock Valley, OR

Characteristics of Vegetation Association Polygons Deliniated during Pre-treatment Juniper Suvey

Polygon	Acres	Juniper Phase	Post-settlement Juniper Stems/Ac.	Dominant Shrubs	Dominant Grasses
1	183	PIPO/JUOC	22	PUTR/ARTRV	FEID
2	61	PIPO/JUOC	27	PUTR/ARTRV	FEID
3	87	PIPO	<5	PUTR/ARTRV	FEID
4	92	1	17	ARTRW/PUTR	FEID
5	24	2	75	ARTRW/PUTR	FEID
6	58	2	27	ARTRW/PUTR	FEID
7	18	2	37	ARTRW/PUTR	FEID
8	26	late 2	40	ARTRW/ERNA	Native Mix
9	162	1	<5	ARTRW/ERNA	Native Mix
10	120	1	<5	ARTRW/ERNA	Native Mix
11	132	1/early2	10 W, 20E	ARTRW/ERNA	Native Mix
12	156	2	50	ARTRW/ERNA	Native Mix
13	42	late 2	40	ARTRW/ERNA	Native /AGCR
14	177	none	0	ERNA/CHVI	Native Mix
15	149	1	20	ARTRW/ERNA	Native /AGCR
16	16	2	42	ARTRW	Native Mix
17	14	2	40	ARTRW	Native Mix
18	32	early 2	30	ARTRW	Native Mix
19	154	1	<5	ERNA/CHVI	Native /AGCR
20	296	1	7	ERNA/ARTRW	Native /AGCR
21	11	2	32	ARTRW	Native Mix
22	420	2	60	ARTRW	Native Mix
23	11	Pre	10	ARTRW	Native Mix
24	7	Pre	10	ARTRW	Native Mix
25	499	1/early 2	25	ARTRW	Native Mix
26	221	1	10	ERNA/ARTRW	Native /AGCR
27	19	1	10	ARTRW/ERNA	Native Mix
28	63	1	10	ARTRW/ERNA	Native Mix
29	46	Pre	35	ARTRW	Native Mix
30	47	Lava	35	ARTRW	Native Mix
31	757	1	10	ERNA/ARTRW	Native /AGCR
32	34	2	52	ARTRW/ERNA	Native Mix
33	451	early 2	17	ARTRW/ERNA	Native /AGCR
34	8	Pre	10	ARTRW	Native Mix

Shrub Abbreviations: ARTRT-basin big sagebrush, ARTRV-mountain big sagebrush, ARTRW- Wyoming big sagebrush, ERNA-Gray Rabbitbrush, CHVI-Green Rabbitbrush, PUTR-bitterbrush

Grass Abbreviations: AGCR-crested wheatgrass, FEID-Idaho fescue

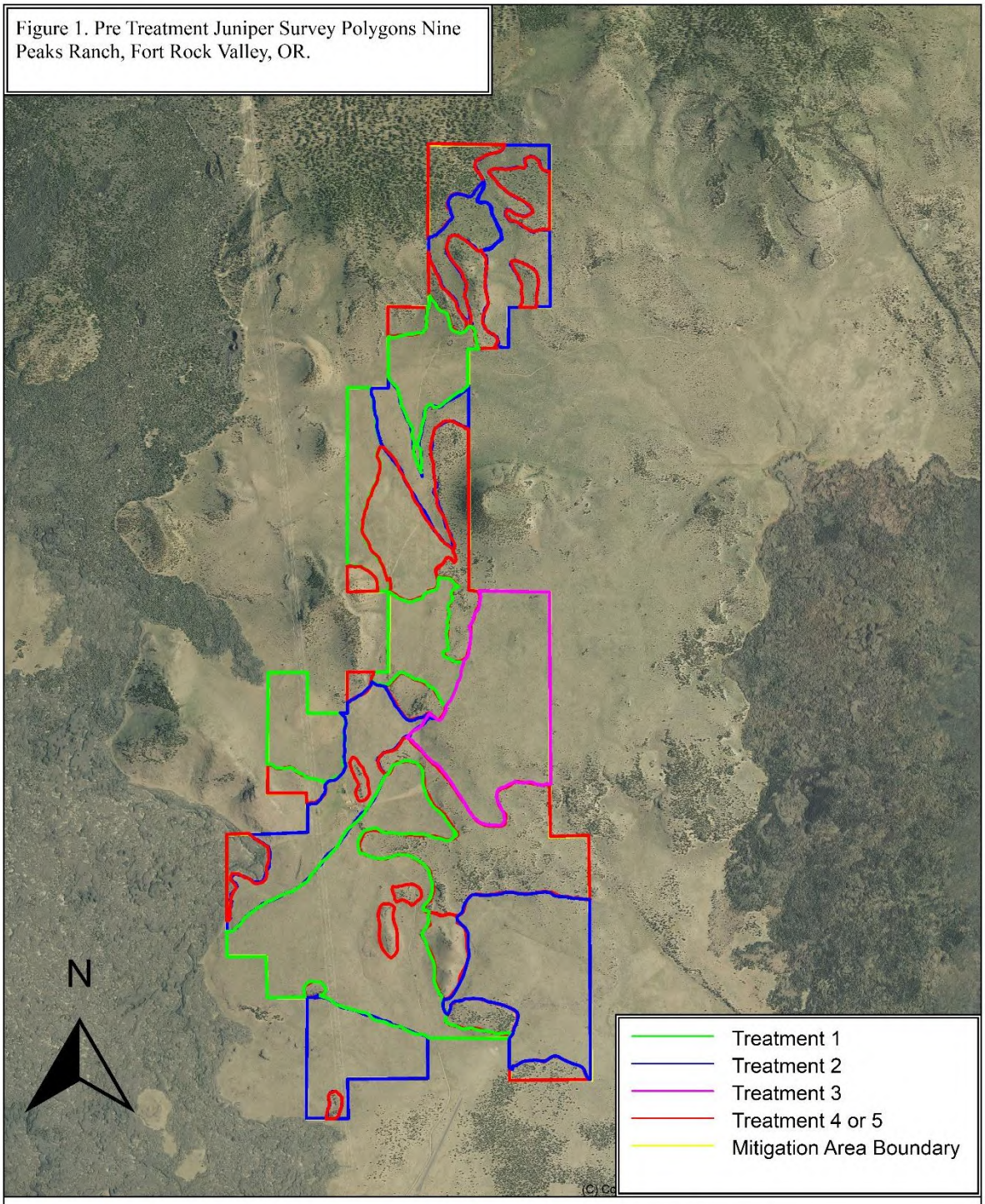
Species in Native Mix: Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, squirrel tail grass, Sandberg's bluegrass, Indian ricegrass

Table 2. Nine Peaks Ranch, Fort Rock Valley, OR

Vegetation Association Polygon Comments

Polygon	Comments
1	Juniper mixed with PIPO - PIPO density decreases going south
2	Juniper codominant with PIPO - substantial number of older trees both species
3	PIPO stand with a few juniper
4	Open JUOC/PIPO codominant stand
5	Rocky ridge
6	Scattered pre-settlement juniper on rock out crops
7	Scattered pre-settlement juniper on rock out crops
11	West leg of polygon has 10 stems/ac; East leg has 20 stems/ac
12	Juniper distribution patchy. Pockets of late 2 and pre-settlement
13	Mixed pre and older post settlement on very rocky soils
17	Rock out crops with scattered pre-settlement
18	Variable juniper density, leave for cover recruitment
20	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
21	Phase 3 on rock out crops
22	Pre-settlement or late phase 2/phase 3 on rock outcrops
	Areas of better soil have early phase 2 juniper @ 25 stems/ac
23	Degraded lava outcrop
24	Degraded lava outcrop
25	Pockets of phase 1 throughout with ~10 stems/ac
26	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
27	Most of polygon burned in wildfire. Shrubs limited
28	Most of polygon burned in wildfire. Pre-settlement remains on rock outcrops
29	Swath on west end that was chained years ago phase 2 with CHNA/ARTRW
30	Aspen clone on east end with very little juniper in aspen
31	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
32	Pre-Settlement JUOC scattered throughout
33	Flatter areas chained years ago and seeded to AGCR, CHNA encroaching
	Remainder of polygon ARTRW with Native bunchgrass mix.
34	Degraded lava outcrop

Figure 1. Pre Treatment Juniper Survey Polygons Nine Peaks Ranch, Fort Rock Valley, OR.

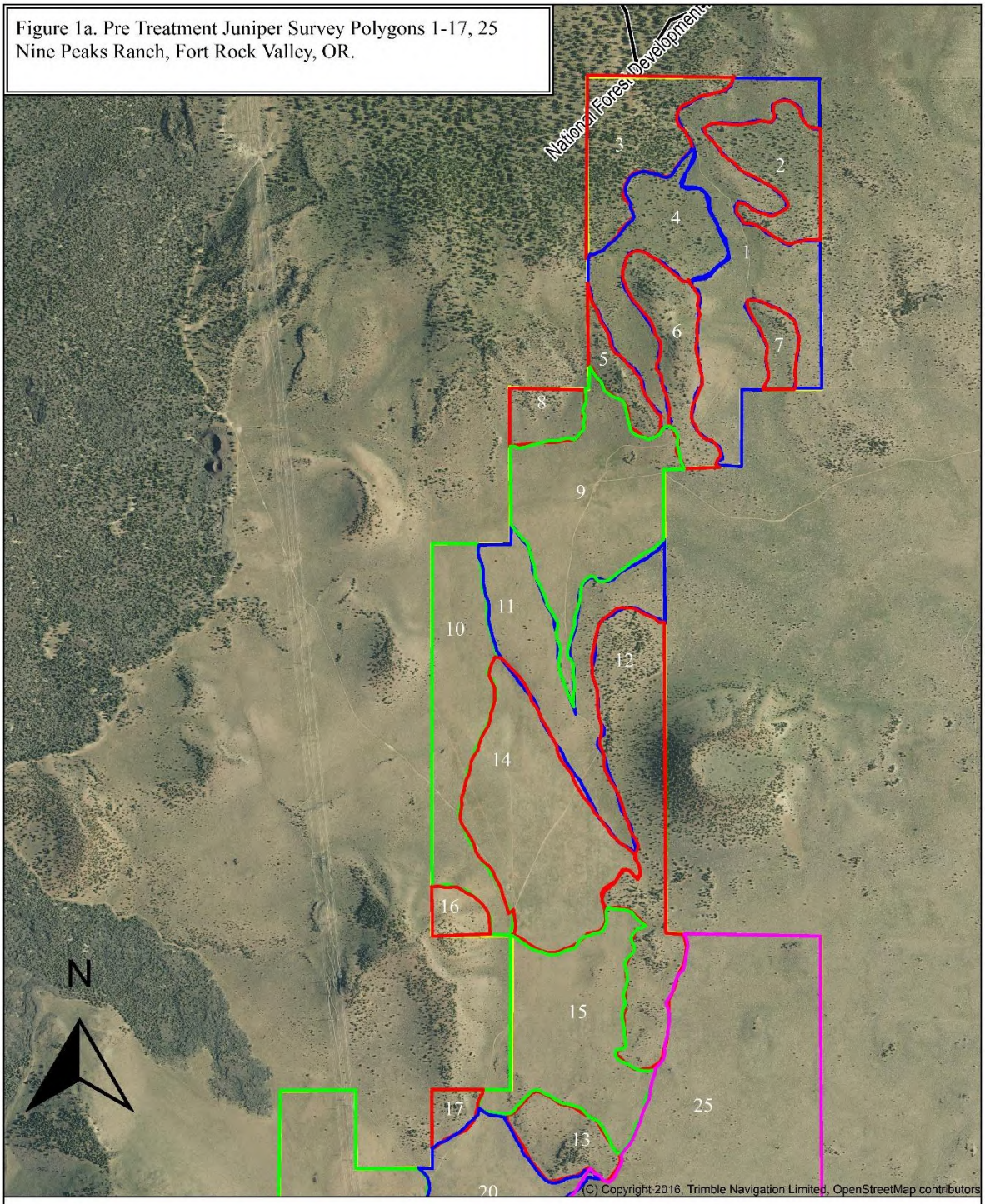


4595 acres
Date: 05/14/20
Scale: 1 inch = 4,000 ft.

Location: 10 0675379 E, 4817258 N
Fosters Natural Resource Contracting

(C) Copyright 2016, Trimble Navigation Limited

Figure 1a. Pre Treatment Juniper Survey Polygons 1-17, 25
Nine Peaks Ranch, Fort Rock Valley, OR.

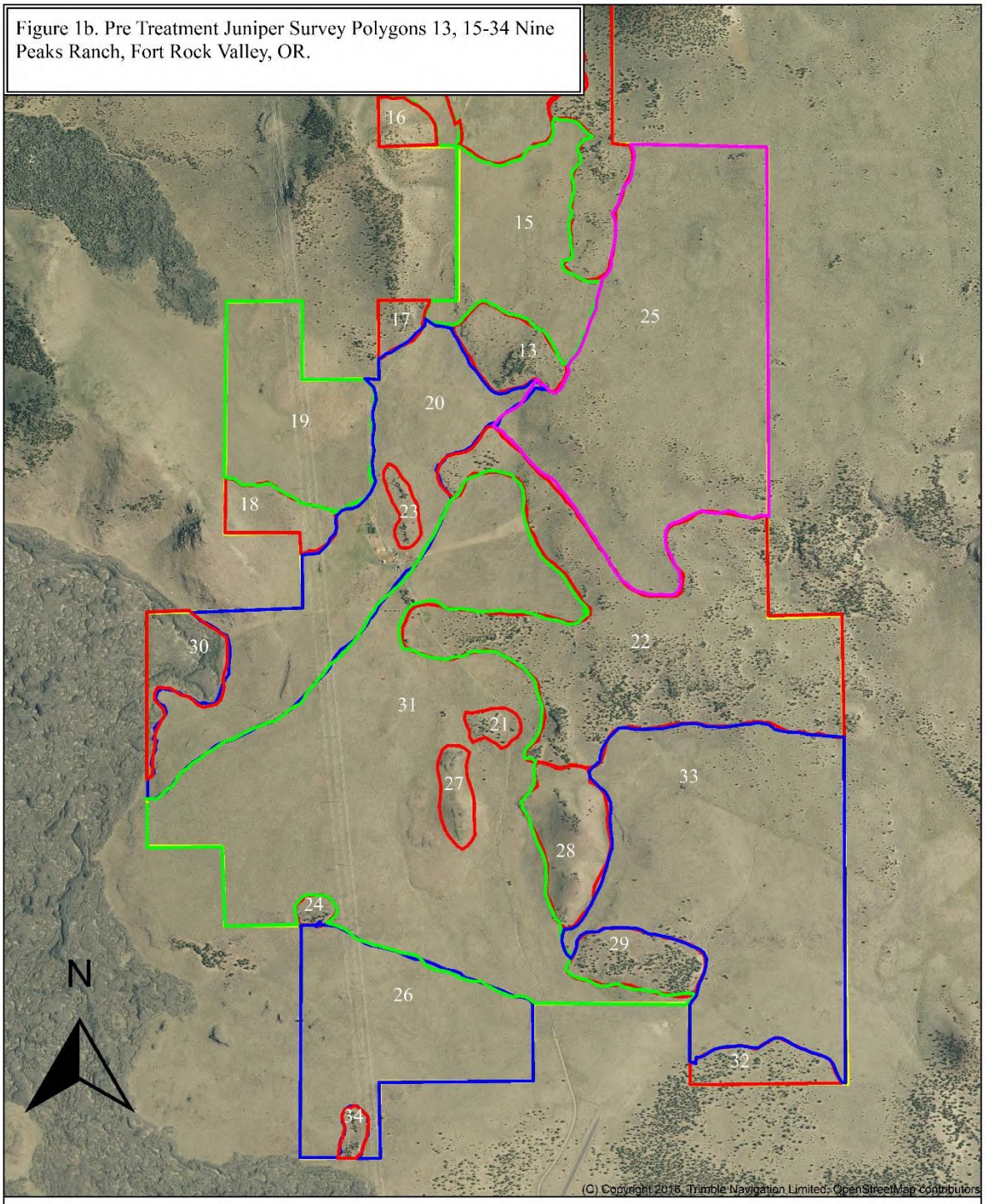


Date: 05/14/20
Scale: 1 inch = 2,083 ft.

Location: 10 0674197 E, 4819051 N
Fosters Natural Resource Contracting

(C) Copyright 2016, Trimble Navigation Limited

Figure 1b. Pre Treatment Juniper Survey Polygons 13, 15-34 Nine Peaks Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 2,083 ft.

Location: 10 0674581 E, 4814974 N
Fosters Natural Resource Contracting

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Morrison Ranch

Field surveys were completed on approximately 1,939 acres in four parcels of the Morrison ranch. Results of the juniper survey are presented in Tables 3 and 4, and Figures 2 and 2a-d. Juniper densities shown in Table 3 were measured using one or more 100 yard X 20 yard (0.4 acre) transects per vegetation association polygon.

Soils are generally sandy to ashy loams with varying amounts of rock. Basalt outcrops and degraded lava flows make up a larger proportion of the Morrison mitigation area than are found on Nine Peaks Ranch. Average annual precipitation is 12 inches, most of which falls as snow in the winter. The Morrison parcels lie within the Paulina wildlife management unit (WMU) on big game winter range designated in the Lake County Comprehensive Land Use Plan.

The property has been managed as a working livestock operation since at least the early 1900's. Valley bottoms with sandy or ashy loam soils were converted to rye (*Secale cereale*) hay fields, then in the 1970's or 1980's those fields were seeded to crested wheatgrass (*Agropyron cristatum*). Gray rabbitbrush (*Ericameria nauseosus*) has established in the crested wheatgrass seedings. Cattle are grazed using a rest rotation system with the exception of the area made up of polygons 41 through 44 (Figure 2b). This area is used as a winter feed area for cattle.

Past management actions or wildfire have resulted in most of the juniper stands on sandy to ashy loam soils being in phase 1 or early phase 2 condition. Pre-settlement or mixed pre-settlement/late phase 2-phase 3 stands are common and occur on degraded lava flows or rock outcrops.

Elevations range from 4750 to 4450 feet. Dominant shrubs are Wyoming big sagebrush and gray rabbitbrush. Native bunch grasses are Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, Indian rice grass, squirrel tail grass and Sandberg's blue grass. Individual pre-settlement juniper is scattered throughout all vegetation associations that have not been converted to crested wheatgrass.

No weed species of concern (Table 1, Attachment 2) were found on either property. Cheatgrass (*Bromus tectorum*), is widely distributed across both properties. Tumble mustard (*Sysimbrium altissimum*) and tansy mustard (*Descurania spp.*) are common in disturbed sites. Although these species are non-native and invasive, they are widely naturalized throughout North America and should not be a specific target of weed control on big game winter range.

Table 3. Morrison Ranch, Fort Rock Valley, OR.

Characteristics of Vegetation Association Polygons Deliniated during Pre-treatment Juniper Suvey

Polygon	Acres	Juniper Phase	Post-settlement Juniper Stems/Ac.	Dominant Shrubs	Dominant Grasses
35	12				
36	29	early 2	50	ERNA	AGCR
37b	19	late 2/3	10	ERNA/ARTRW	FEID/AGCR
38	44	Pre	10	ARTRW/ERNA	Native Mix
39b	22	late 2/3	27	ARTRW/ERNA	Native Mix
40b	104	1	12	ERNA/CHVI	AGCR
41	39	Pre	10	ERNA/CHVI	Native Mix
42	99	1	<5	ERNA/CHVI	Native Mix
43	106	Pre	5	ERNA/CHVI	Native Mix
44	233	Pre	<5	ERNA/CHVI	Native Mix
45	140	Pre	25	ARTRW/ARTRT	Native Mix
46	30	2	17	ARTRW/ERNA	Native Mix
47	111	1	12	ARTRW/ERNA	Native/AGCR
48	34	Pre	<5	ERNA/ARTRW	Native/AGCR
49	48	1	15	ERNA/CHVI	AGCR
50	103	1	20	ERNA/ARTRW	AGCR
51	174	1	<5	ERNA/ARTRW	AGCR
52	20	1	15	ARTRW/ERNA	Native Mix
53	24	1	22	ARTRW/ERNA	FEID
54	7	1	20	ARTRW/ERNA	FEID
55	4	1	15	ARTRW/ERNA	Native Mix
56	28	1	15	ARTRW/ERNA	Native Mix
57	5	Pre	17	ERNA/ARTRW	Native Mix
58	50	Pre	17	ERNA/ARTRW	Native Mix
59	10	Pre	15	ERNA/ARTRW	Native Mix
60	179	Pre	5	ERNA/ARTRW	Native Mix
61	208	Pre	27	ARTRW/ERNA	Native Mix
62	46	early 2	17	ARTRW/ERNA	Native Mix
63	44	1	7	ARTRW/ERNA	Native Mix
64	27	early 2	55	ARTRW/ERNA	Native Mix

Shrub Abbreviations: ARTRT-basin big sagebrush, ARTRV-mountain big sagebrush, ARTRW- Wyoming big sagebrush, ERNA-Gray Rabbitbrush, CHVI-Green Rabbitbrush

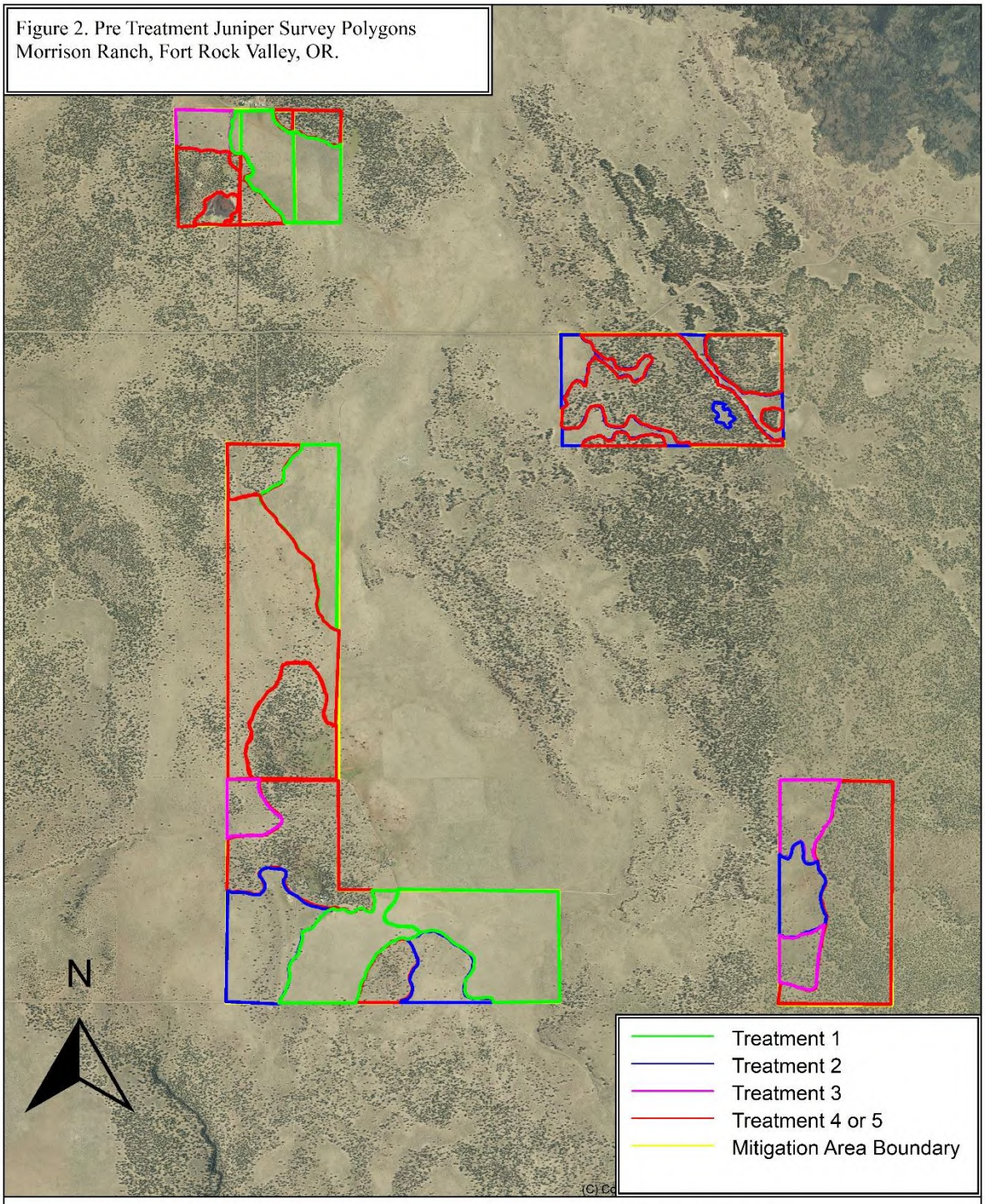
Grass Abbreviations: AGCR-crested wheatgrass, FEID-Idaho fescue

Species in Native Mix: Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, squirrel tail grass, Sandberg's bluegrass, Indian ricegrass

Table 4. Morrison Ranch, Fort Rock Valley, OR.
Vegetation Association Polygon Comments

Polygon	Comments
35	Cinder Pit
37b	Scattered pre-settlement throughout. Probably was a pre-settlement stand but ~ 100 years ago most trees cut - being replaced with older Post-settlement trees
	Polygon 37a is 22 acres
38	Post settlement trees are 10/ac of trees ~80 years old and <5/ac of trees ~20 years old
39b	Scattered pre-settlement throughout. Polygon 39a is 4 acres
40b	Juniper distribution patchy- large areas of <5 stems/ac. Polygon 40a is 60 acres.
41	Within winter feed lot. Shrubs very sparse.
42	Within winter feed lot. Shrubs very sparse.
43	Denser stand of Pre-settlement and old Post-settlement trees. JUOC <40 years are <5/ac.
	Within winter feed lot. Shrubs very sparse.
44	Sparse stand of pre-settlement. Post-settlement trees ~ 20 yrs old and <5/ac
45	A portion of the area west of the road was an old feed lot. In this area
	post settlement <5/ac. Shrubs CHNA/CHVI.
46	Scattered Pre-settlement throughout.
47	Scattered Pre-settlement throughout.
49	Scattered Pre-settlement throughout.
50	Old rye hay field converted to AGCR ~ 40 years ago
51	Old rye hay field converted to AGCR ~ 40 years ago
52	Ward Well #1 on tablet pictures
53	Shallow draw bottom between degrading lava flows. Ward Well #4 on tablet pictures
54	Shallow draw bottom between degrading lava flows.
55	Better soil inclusion in degraded lava flow
56	Shallow draw between degraded lava flows. Juniper density increases south to north
57	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
58	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
59	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
60	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
62	Scattered Pre-settlement throughout.
63	Scattered Pre-settlement throughout.
64	Scattered Pre-settlement throughout.

Figure 2. Pre Treatment Juniper Survey Polygons
Morrison Ranch, Fort Rock Valley, OR.

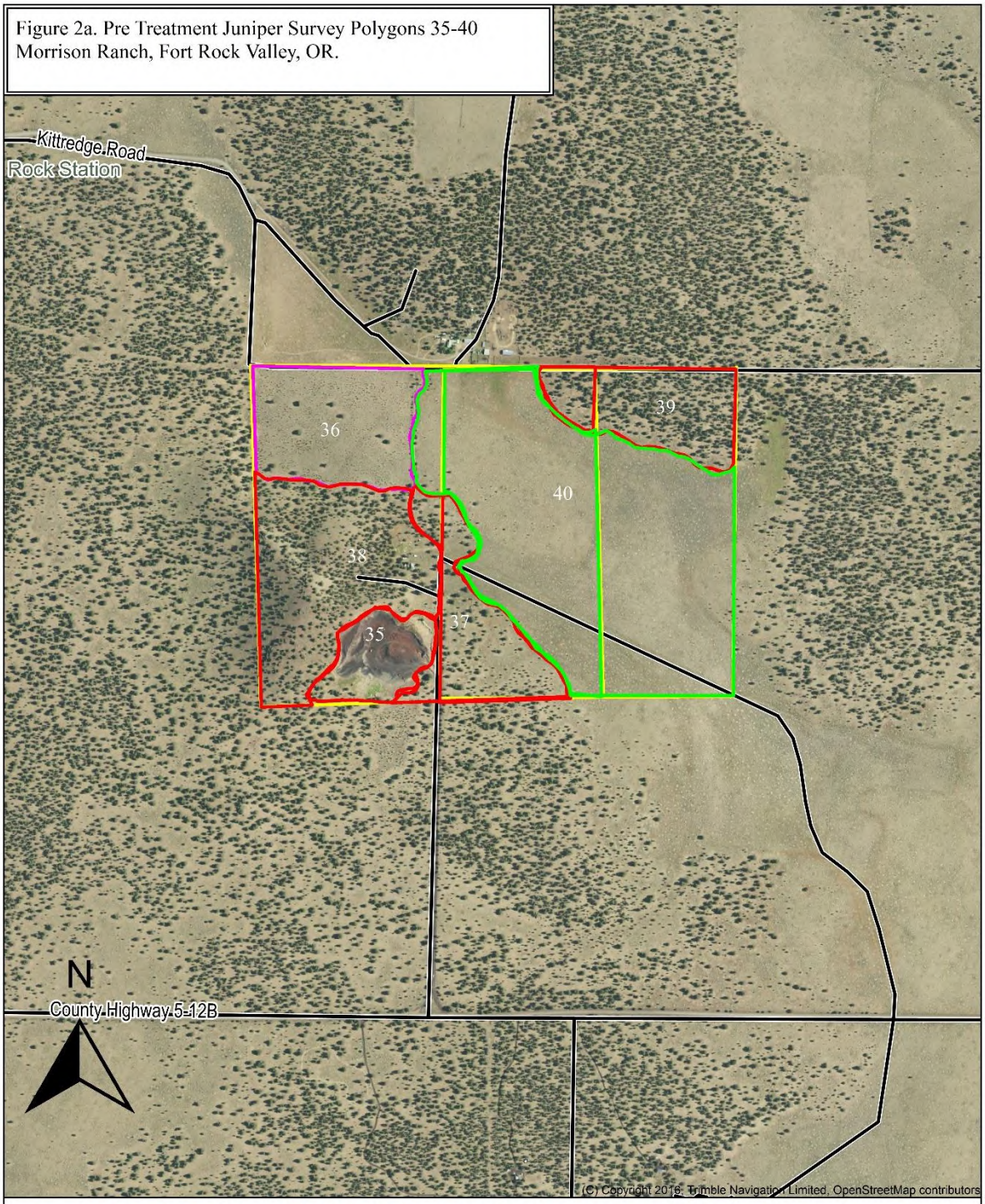


1939 acres
Date: 05/14/20
Scale: 1 inch = 2,916 ft.

Location: 10 0678120 E, 4807203 N
Fosters Natural Resource Contracting

(C) Copyright 2016, Trimble Navigation Limited

Figure 2a. Pre Treatment Juniper Survey Polygons 35-40
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0676334 E, 4810132 N
Fosters Natural Resource Contracting

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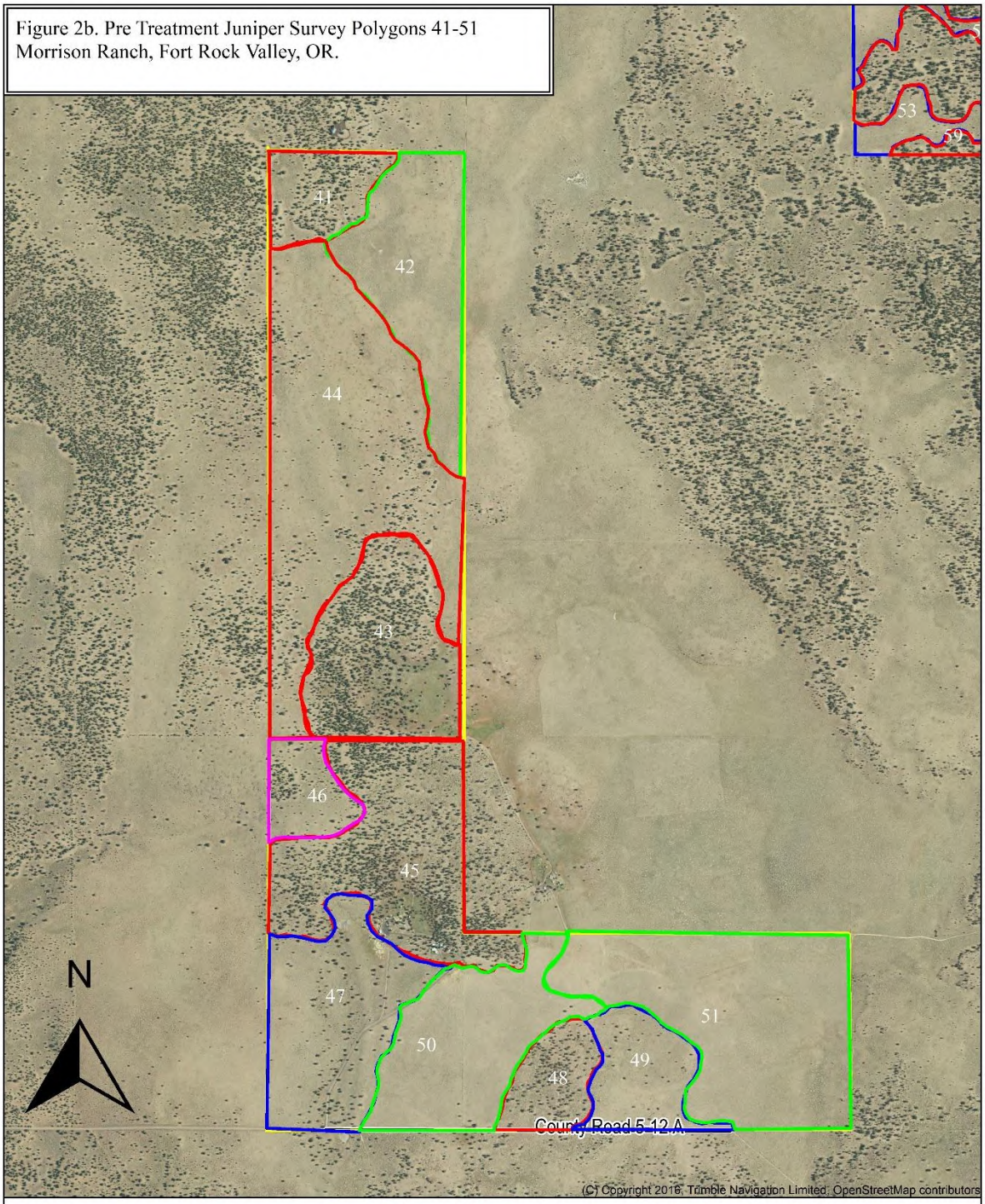
Figure 2b. Pre Treatment Juniper Survey Polygons 41-51
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,666 ft.

Location: 10 0677139 E, 4806452 N
Fosters Natural Resource Contracting

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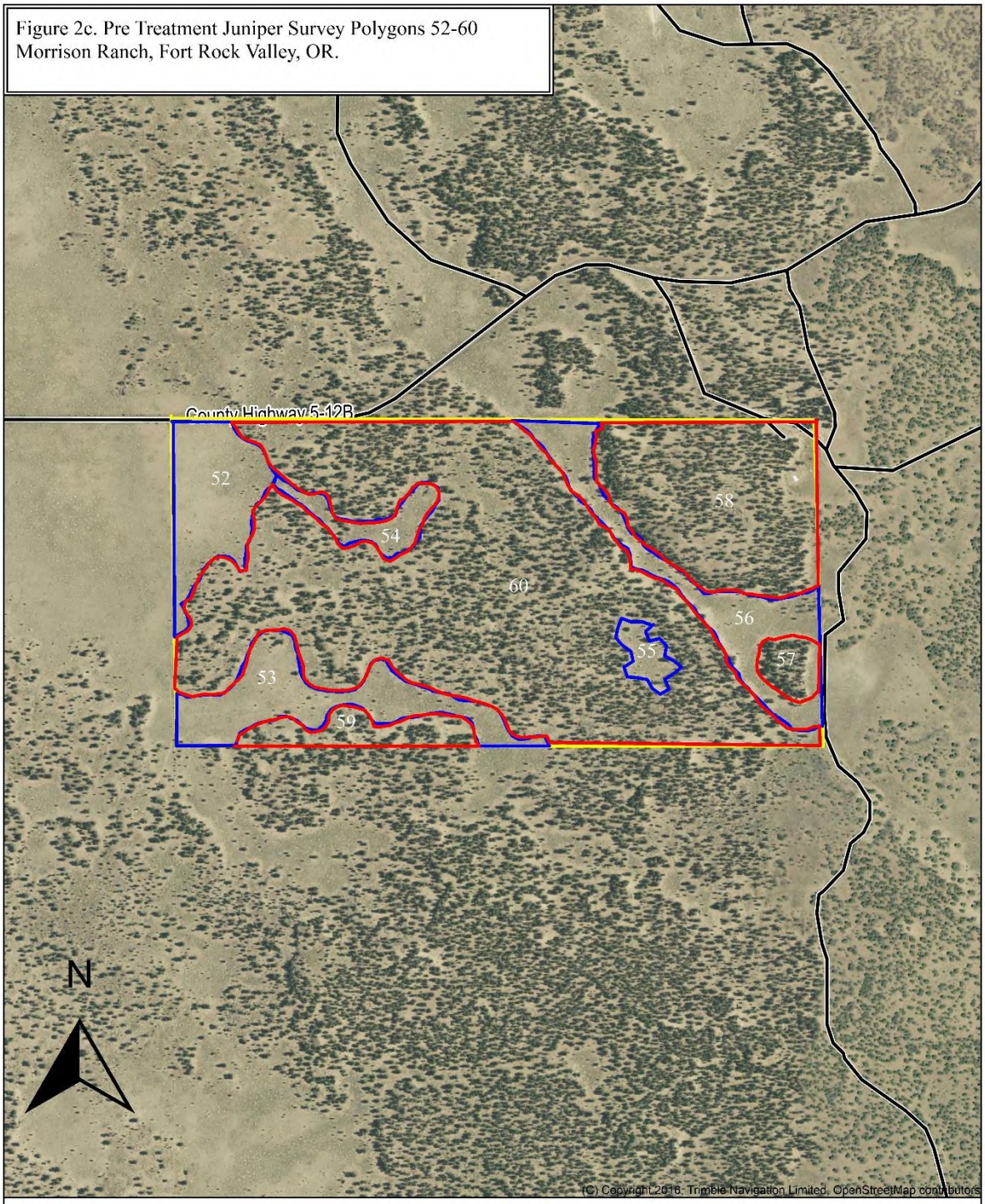
Figure 2c. Pre Treatment Juniper Survey Polygons 52-60
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0679375 E, 4808720 N
Fosters Natural Resource Contracting

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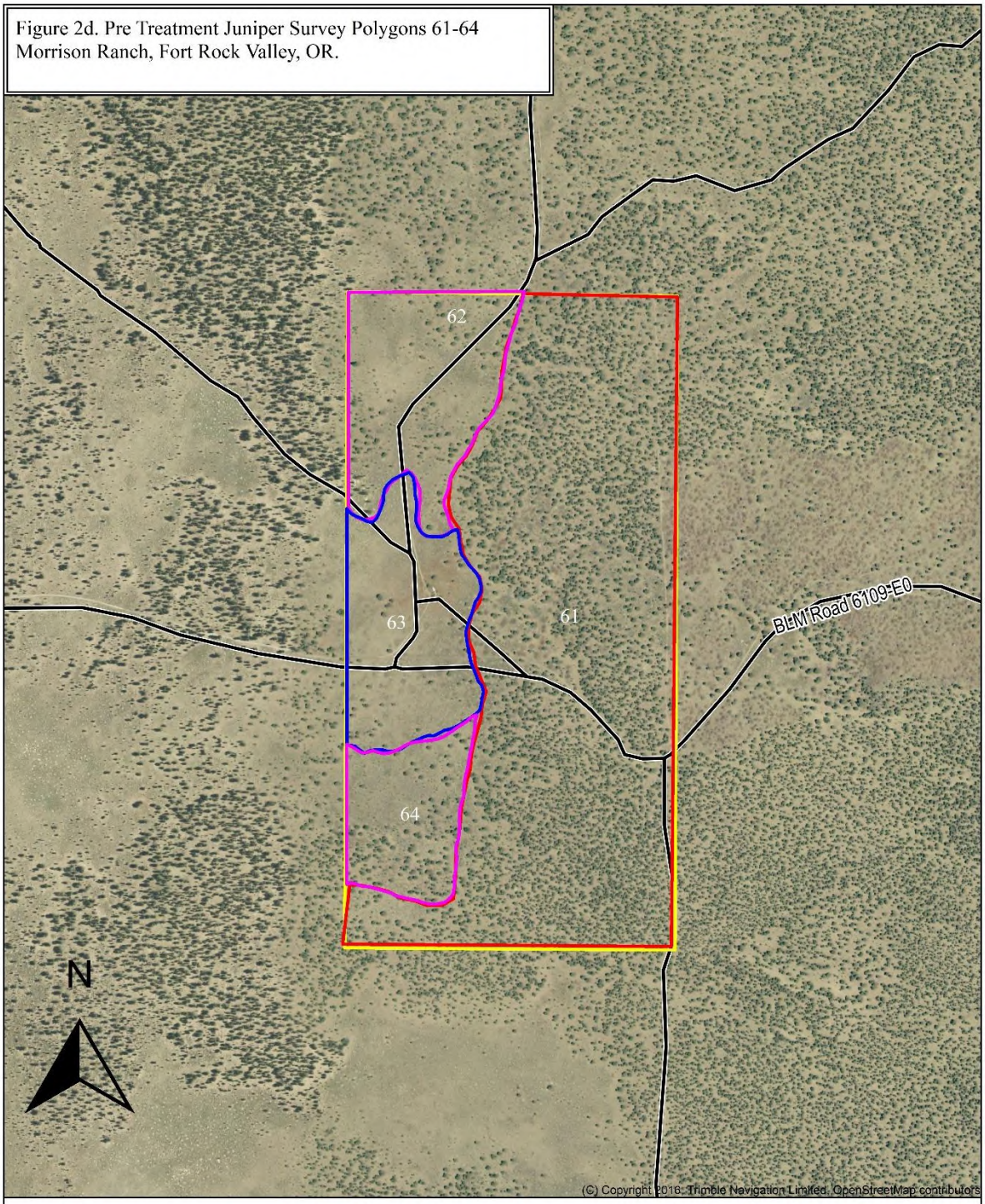
Figure 2d. Pre Treatment Juniper Survey Polygons 61-64
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0680626 E, 4805201 N
Fosters Natural Resource Contracting

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Conclusions

In their existing condition the mitigation properties have a better mosaic of forage and cover areas for big game winter range than what is available on the Facility. Vegetation associations on the Facility are 95% sagebrush shrubland and the remaining 5% does not include forest vegetation associations. The mitigation properties currently have a forage:cover ratio of 62:38 (Nine Peaks 70:30, Morrison 45:55). However, juniper encroachment into the forage areas, if left unchecked will reduce forage quality and quantity. Juniper treatments in the mitigation area are designed to reduce juniper encroachment in sagebrush shrubland vegetation associations, and recruit or protect cover values in the forest vegetation associations which will maintain and improve habitat values for wintering big game.

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Appendix 1

WLIP Site Habitat Assessment Protocol

Prepared For:

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Introduction

Obsidian Solar Center LLC (Obsidian) is applying for a Site Certificate from the Oregon Energy Facilities Siting Council to build and operate the Obsidian Solar Facility in the Fort Rock Valley of Lake County, Oregon. A condition of the certificate will require Obsidian to mitigate for the facility's impacts to Category 2 big game winter range habitat and they have submitted a draft Habitat Mitigation Plan (HMP) for review and approval (Attachment 1). The HMP proposes establishment of a Working Lands Improvement Program (WLIP) on two properties totaling 6,534 acres in the Fort Rock Valley (HMP Attachment 3). The HMP identifies 5 steps to establish the WLIP (HMP Section 3.3, page 8). The purpose of this document is to describe the methods to complete a general habitat assessment of big game winter range and a pre-treatment inventory of juniper stands and weeds on the WLIP properties.

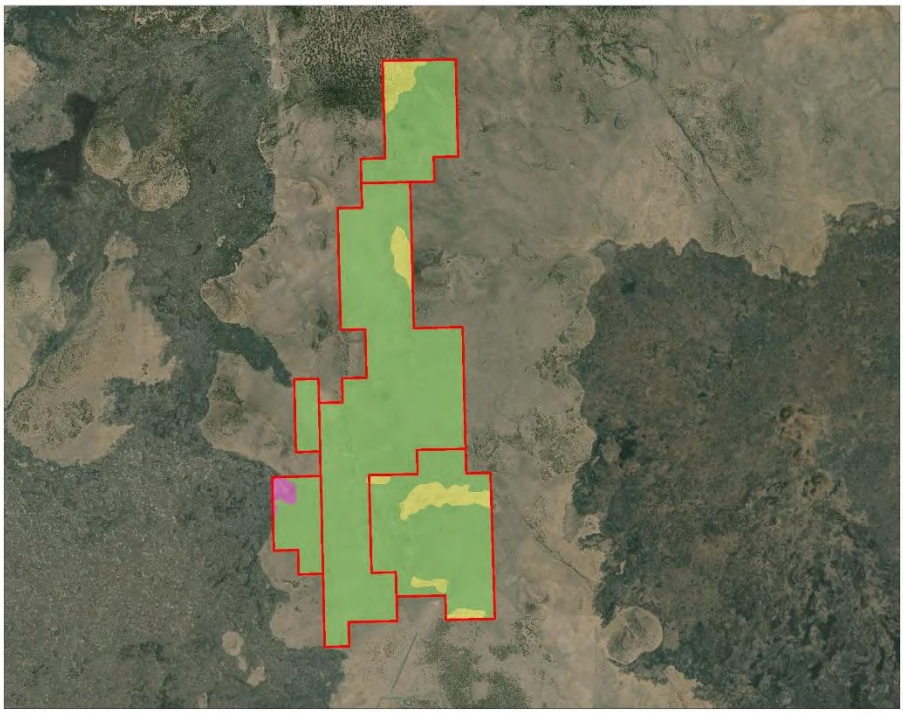
Habitat Assessment Protocol

Figures 1a and 1b from the HMP (Attachment 1) identifies juniper woodland, non-native grassland and sagebrush shrubland as the vegetative types on the WLIP properties. It is very difficult to differentiate grass and shrub species from a desk top classification using photo imagery. The purpose of the habitat assessment is to better define plant associations and delineate their boundaries. The assessment will focus on forage and cover conditions for big game species, specifically mule deer (*Odocoileus hemionus*) and rocky mountain elk (*Cervus elaphus nelsoni*), by walking variable width transects throughout the 6,534 acres within the various plant associations to determine species present and vegetative condition. Transect width needs to be determined by the vegetative condition present at the time of inventory (e.g. delineating the boundary of a noxious weed infestation will require substantially tighter transect lines than determining the size and condition of a crested wheatgrass seeding), which will be conducted in Spring (April – May). The habitat assessment may be conducted in Summer or Fall, if completed by individuals experienced in plant identification when desiccated.

A biological assessment (Obsidian Solar, Biological Assessment, 2018 Unpubl. Report) of the solar development properties determined the primary impact to big game winter habitat was loss of forage. The primary forage species available in the Fort Rock Valley are sage brush, bitterbrush and perennial forbs for deer, and those species plus native and non-native grass for elk. Coe et al. (2017) reported that juniper stands are selected for winter habitat by deer and numerous studies have shown the importance of winter cover for elk. Cover availability will be determined during the juniper inventory.

Assessment of the non-native grassland association will identify: Dominate species and condition of grass, and perennial forbs. Dominate species and condition of shrubs (if any). Level of juniper encroachment. Assessment of the sagebrush shrubland association will identify: Dominate species and condition of shrubs. Level of juniper encroachment. Presence and species

of native grasses and forbs. Boundaries of vegetation associations will be delineated using GPS and mapped.



Stantec

Potential Mitigation Area
Quarry
Habitat Types
Juniper Woodland
Non-Native Grassland
Sagebrush Shrubland

N

0 2,000 4,000 Feet

1 in = 4,000 feet

Project Location
Lake County, Oregon

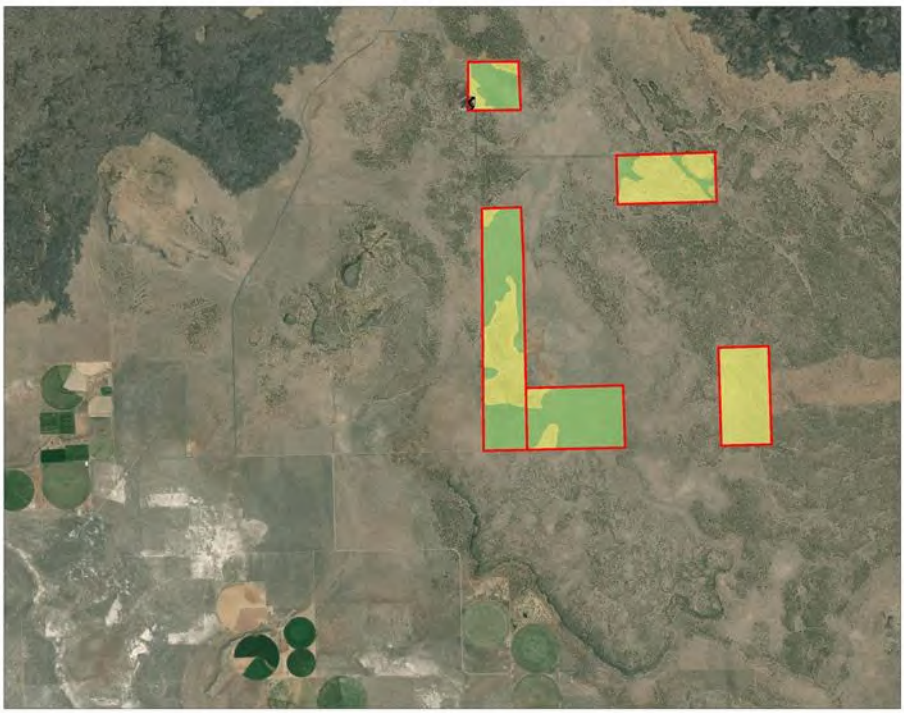
Prepared by BRT on 2020-02-10
TR by DR on 2020-02-11

Client/Project
165704672

Obsidian Solar LLC
Obsidian Solar Center

Title
Figure 1A. Habitat Types in the Mitigation Area on Borror Property

Disclaimer: This document has been prepared based on information provided by others as cited in the Notes section. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.



Stantec

Potential Mitigation Area
Quarry
Habitat Types
Juniper Woodland
Non-Native Grassland
Sagebrush Shrubland

N

0 2,000 4,000 Feet

1 in = 4,000 feet

Project Location
Lake County, Oregon

Prepared by BRT on 2020-02-10
TR by DR on 2020-02-11

Client/Project
165704672

Obsidian Solar LLC
Obsidian Solar Center

Title
Figure 1B. Habitat Types in the Mitigation Area on Morrison Property

Disclaimer: This document has been prepared based on information provided by others as cited in the Notes section. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Juniper Inventory

Juniper stands will be classified to Phase. Age of juniper within the stands will be defined as either pre or post settlement (Miller et al., 2007). Below is the juniper Phase classification which will be used.

Phase 1 stands are defined as having post-settlement juniper that are either not abundant or old enough to compete with shrubs as indicated by the majority of the shrubs in the stand being robust with few or no dead limbs. Perennial herbaceous vegetation is abundant and bare soil is > 50%

Phase 2 stands have post-settlement juniper that are abundant and old enough to impact shrub growth, and shrub or herbaceous species establishment, which usually results in greater than 50% bare soil. Phase 2 stands are further defined as being early or late: Shrubs in early Phase 2 stands are still relatively abundant but dead limbs within individual plants are common. Skeletons of dead shrubs are common throughout the stand and seedling shrubs are uncommon. Shrubs in late Phase 2 stands are common but there are more dead than live limbs within individual plants. Skeletons of dead shrubs are common throughout the stand and seedling shrubs are absent or restricted to a few individual plants.

Phase 3 stands have pre and/or post-settlement juniper that are abundant and old enough to have out competed most of the shrubs in the understory. Shrubs remaining are stunted with few live limbs and bare soil usually exceeds 70%, unless nonnative annual grasses have encroached into the stand. Skeletons of dead shrubs are generally uncommon because they have already broken down.

Pre-settlement juniper are older than 200 years and established prior to or at the approximate time of European settlement of the western U.S. Within the Fort Rock Valley, they occur as individual trees within a younger stand or as distinct stands of juniper dominated by pre-settlement trees.

Boundaries of juniper stands will be delineated using GPS and mapped. If individual pre-settlement juniper trees are found their location will be recorded so they can be retained in any scheduled treatment.

Noxious Weed Inventory

A noxious weed inventory will be conducted on the WLIP properties. All disturbed sites, roads and areas near water will be surveyed for noxious weeds (Table 1), medusa head rye (*Taeniatherum caput-medusae*) and ventenata (*Ventenata dubia*). The location and boundaries of any infestations found will be recorded using GPS and mapped. Additionally, the location and boundaries of all infestation found during the habitat assessment and juniper inventory will be recorded using GPS and mapped, (Bartz, 2006).

Table 1: Weed Species of Concern

Weed Species Common Name	Scientific Name	Threat Level
Canada Thistle	*Cirsium arvense*	3
Common Reed	*Phragmites australis, ssp. Australis*	0
Cutleaf teasel	*Dipsacus Laciniatus*	1
Dalmatian toadflax	*Linaria dalmatica*	2
Diffuse knapweed	*Centaurea diffusa*	1
Dyer's Woad	*Isatis tinctoria*	3
Eurasian watermilfoil	*Myriophyllum spicatum*	0
Field Bindweed	*Convolvulus arvensis*	1
Hoary Cress (whitetop)	*Lepidium draba,Lepidium et. Al*	2
Kochia	*Kochia scoparia*	3
Leafy Spurge	*Euphorbia esula*	0
Mediterranean sage	*Salvia aethiopis*	3
Medusahead rye	*Taeniatherum caput-medusae*	3
Musk thistle	*Carduus nutans*	2
Myrtle Spurge	*Euphorbia myrsinites*	2
Perennial Pepperweed	*Lipidium latifolium*	1
Puncturevine	*Tribulus terrestris*	2
Purple loosestrife	*Lythrum salicari*	1
Rush Skeletonweed	*Chondrilla juncea*	0
Russian knapweed	*Acroptilon repens*	1
Saltceder	*Tamarix ramosissima*	1
Scotch broom	*Cytisus scoparius*	0
Scotch thistle	*Onopordum acathium*	3
Spotted Knapweed	*Centaurea stoebe (c.maculosa)*	2
Spinny Cockelbur	*Xanthium spinosum*	3
Summer Pheasant eye	*Adonis vernailis*	2
Sulfur cinquefoil	*Potentilla recta*	2
Yellow Starthistle	*Centaurea solstitialis*	1
Yellow Toadflax	*Linaria vulgaris*	3

Threat key

0 Watch For
1 Establishing
2 Controllable
3 Widespread
x Not detected

Literature Cited

Bartz, E., 2006. Noxious weed plan. Las Vegas Field Office, Nevada BLM: A plan for integrated weed management. Appendix 3: Weed Survey Protocol. Unpubl. Report. pp. 16-17.

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Attachment 1

Obsidian Solar Center Habitat Mitigation Plan

(Provided Under Separate Attachment)

Attachment 2

Obsidian Solar Center

2018 Habitat Assessment and Biological Resources Field Report

(Provided Under Separate Attachment)

Juniper Treatment Plan

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Introduction

Obsidian Solar Center LLC (Obsidian) is applying for a site certificate from the Oregon Energy Facilities Siting Council (EFSC) to build and operate the Obsidian Solar Facility in the Fort Rock Valley of Lake County, Oregon (Facility). A condition of the site certificate will require Obsidian to mitigate for the Facility's impacts to Category 2 big game winter range habitat. Obsidian has developed a Habitat Mitigation Plan (HMP). The HMP proposes to establish a Working Lands Improvement Program (WLIP) on portions of two properties, totaling 6,534 acres in the Fort Rock Valley (HMP Attachment 3). The total acreage enrolled in the WLIP will depend on the permanent footprint from the Facility's final design. The WLIP is two-fold: it involves habitat protection under a WLIP landowner agreement, and big game winter habitat enhancement using a juniper treatment program. The HMP identifies 5 steps to implement the juniper treatment and management program (HMP Section 3.3, page 8). Steps 1 and 2 involves completing a pre-treatment juniper (*Juniperus occidentalis*) field survey and developing a juniper treatment plan for the two properties. The purpose of this document is to present the juniper treatment plan (Step 2).

The goal of the WLIP is to provide mitigation by maintaining and improving big game winter habitat on the mitigation properties. Winter range will be maintained by establishing a WLIP agreement with the landowners. Big game winter range will be improved by providing a mosaic of vegetation associations designed to provide big game cover and forage areas across the properties. Juniper encroachment into shrub steppe habitats results in reduced forage quality and quantity due its ability to out compete shrubs and bunchgrass (Vaitkas and Eddleman 1987, Miller and Rose 1999, Miller et al. 2005, Davies et al. 2011). Forest vegetation associations are an important habitat component for wintering big game as they provide both thermal and hiding cover (Leckenby and Adams 1986, Boyce et al. 2003, Coe et al. 2018). Juniper woodlands are the primary forest habitat available during winter in the Fort Rock Valley (Coe et al. 2018). Therefore, actions under the HMP are not designed to just cut juniper, but are intended to provide quality winter habitat on the properties.

Pre-treatment juniper field surveys were completed during the first 2 weeks of April and the second week of May, 2020 (Appendix 1), using the Obsidian habitat assessment protocol (Appendix 2) approved by Oregon Department of Energy (ODOE) in consultation with Oregon Department of Fish and Wildlife (ODFW). Information collected during those surveys along with suggestions provided in Miller el al. (2007) and Barrett (2007) were used to develop the juniper treatment plan for improving habitat conditions on big game winter range.

Juniper Treatment Plan

The purpose of this mitigation is to improve big game winter range by developing a mosaic of forage and cover areas. This will be accomplished by maintaining the quality of forage areas by removing juniper in phase 1and 2 stands in order to retard juniper encroachment and its effect on

understory vegetation, and retain juniper in pre-settlement and/or late phase 2 or phase 3 stands to provide cover.

Juniper treatments selected are shown in Tables 1 through 4 and Figures 1; 1a and b; 2; 2a-d. Vegetation associations were defined based on phase of juniper stands, understory vegetation present and land management practices which would affect treatment decisions. For example, polygon 26 on Nine Peaks Ranch has a low density stand of Phase 1 juniper and two understory plant associations (Table 2). The polygon is being treated to maintain forage. Juniper density and age are similar across the polygon, and treatment would not be different between the two understory plant associations. Similarly, there are areas of phase 1 and early phase 2 juniper within some cover polygons which were not identified for treatment in order to recruit future cover values (e.g. phase 1 and 2 inclusions between pre-settlement juniper in polygon 22 (Fig. 1b) on Nine Peaks Ranch). Finally, some of the pre-settlement or late phase juniper stands have encroachment of younger juniper (<60 years old) dense enough to provide fuel connectivity and put the stand at risk in the event of a wildfire (e.g. polygon 60, Morrison Ranch, Fig. 2c). Removing some or all of the younger juniper would be beneficial in terms of stand retention but this was weighed against the impact to cover value or potential impact to rock or lava structure and understory vegetation if machinery is used for treatment.

Treatments 1 through 3 below are designed to reduce juniper encroachment into vegetation associations managed for forage areas. Treatments 4 and 5 are designed to recruit or maintain vegetation associations managed for cover.

Methods Common to all Treatment Options

Irrespective of juniper phase or treatment prescription all pre-settlement juniper and ponderosa pine will not be cut. In the pre-settlement or late phase 2 or phase 3 stands which are designated for cover all post settlement juniper that have open trunks will not be cut. Open trunks mean the juniper has no live limbs from ground level up approximately 4 feet (Figure 3). In areas with post-settlement encroachment scattered individual juniper, or if available, clumps of juniper with open trunks will be retained for big game cover and/or livestock shade trees. In areas with high densities of these types of juniper it may be necessary to mark juniper to be retained.

Small isolated rock out crops or lava eruptions occur in many of the polygons. These outcrops have old individual juniper trees and provide unique wildlife habitat (Figure 4). All juniper on these small out crops will not be cut.

Juniper treatment on private lands in Oregon require a permit issued by Oregon Department of Forestry. The reason for this permit is to ensure treatment activities do not result in excessive fuel loading which in the event of a wildfire would compromise suppression efforts. There is no cost to secure a permit but the permit needs to be approved before juniper cutting begins. Permits are issued to the property owner and approved for one year. Permits need to be re-issued annually if treatment activities continue for more than a year. Failure to secure a permit results in the landowner being liable for wildfire suppression costs if it is determined that the juniper treatment resulted in excessive untreated fuel loading which in the event of a wildfire exacerbated suppression efforts.

During the first land surveys in Oregon section and quarter section corner marks were blazed into trees. These marks are now more than 100 years old and have antiquities value. Although we are not cutting any pre-settlement trees the Lake County Surveyor requires juniper treatment plans be reviewed for potential impact to these trees and if necessary, the Surveyor will visit the treatment areas, record the location of these trees and mark them for retention.

Table 1. Nine Peaks Ranch, Fort Rock Valley, OR

Characteristics of Vegetation Associations and Juniper Treatment Prescriptions

Polygon	Acres	Juniper Phase	Post-settlement Juniper Stems/Ac.	Dominant Shrubs	Dominant Grasses	Juniper Treatment
1	183	PIPO/JUOC	22	PUTR/ARTRV	FEID	2
2	61	PIPO/JUOC	27	PUTR/ARTRV	FEID	5
3	87	PIPO	<5	PUTR/ARTRV	FEID	5
4	92	1	17	ARTRW/PUTR	FEID	2
5	24	2	75	ARTRW/PUTR	FEID	5
6	58	2	27	ARTRW/PUTR	FEID	5
7	18	2	37	ARTRW/PUTR	FEID	5
8	26	late 2	40	ARTRW/ERNA	Native Mix	5
9	162	1	<5	ARTRW/ERNA	Native Mix	1
10	120	1	<5	ARTRW/ERNA	Native Mix	1
11	132	1/early2	10 W, 20E	ARTRW/ERNA	Native Mix	2
12	156	2	50	ARTRW/ERNA	Native Mix	5
13	42	late 2	40	ARTRW/ERNA	Native /AGCR	5
14	177	none	0	ERNA/CHVI	Native Mix	5
15	149	1	20	ARTRW/ERNA	Native /AGCR	1
16	16	2	42	ARTRW	Native Mix	5
17	14	2	40	ARTRW	Native Mix	5
18	32	early 2	30	ARTRW	Native Mix	5
19	154	1	<5	ERNA/CHVI	Native /AGCR	1
20	296	1	7	ERNA/ARTRW	Native /AGCR	2
21	11	2	32	ARTRW	Native Mix	5
22	420	2	60	ARTRW	Native Mix	5
23	11	Pre	10	ARTRW	Native Mix	5
24	7	Pre	10	ARTRW	Native Mix	5
25	499	1/early 2	25	ARTRW	Native Mix	3
26	221	1	10	ERNA/ARTRW	Native /AGCR	2
27	19	1	10	ARTRW/ERNA	Native Mix	5
28	63	1	10	ARTRW/ERNA	Native Mix	5
29	46	Pre	35	ARTRW	Native Mix	4
30	47	Lava	35	ARTRW	Native Mix	5
31	757	1	10	ERNA/ARTRW	Native /AGCR	1
32	34	2	52	ARTRW/ERNA	Native Mix	5
33	451	early 2	17	ARTRW/ERNA	Native /AGCR	2
34	8	Pre	10	ARTRW	Native Mix	5

Shrub Abbreviations: ARTRT-basin big sagebrush, ARTRV-mountain big sagebrush, ARTRW- Wyoming big sagebrush, ERNA-Gray Rabbitbrush, CHVI-Green Rabbitbrush, PUTR-bitterbrush

Grass Abbreviations: AGCR-crested wheatgrass, FEID-Idaho fescue

Species in Native Mix: Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, squirrel tail grass, Sandberg's bluegrass, Indian ricegrass

Table 2. Nine Peaks Ranch, Fort Rock Valley, OR

Vegetation Association Polygon Comments

Polygon	Comments
1	Juniper mixed with PIPO - PIPO density decreases going south
2	Juniper codominant with PIPO - substantial number of older trees both species
3	PIPO stand with a few juniper
4	Open JUOC/PIPO codominant stand
5	Rocky ridge
6	Scattered pre-settlement juniper on rock out crops
7	Scattered pre-settlement juniper on rock out crops
11	West leg of polygon has 10 stems/ac; East leg has 20 stems/ac
12	Juniper distribution patchy. Pockets of late 2 and pre-settlement
13	Mixed pre and older post settlement on very rocky soils
17	Rock out crops with scattered pre-settlement
18	Variable juniper density, leave for cover recruitment
20	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
21	Phase 3 on rock out crops
22	Pre-settlement or late phase 2/phase 3 on rock outcrops
	Areas of better soil have early phase 2 juniper @ 25 stems/ac
23	Degraded lava outcrop
24	Degraded lava outcrop
25	Pockets of phase 1 throughout with ~10 stems/ac
26	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
27	Most of polygon burned in wildfire. Shrubs limited
28	Most of polygon burned in wildfire. Pre-settlement remains on rock outcrops
29	Swath on west end that was chained years ago phase 2 with CHNA/ARTRW
30	Aspen clone on east end with very little juniper in aspen
31	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
32	Pre-Settlement JUOC scattered throughout
33	Flatter areas chained years ago and seeded to AGCR, CHNA encroaching
	Remainder of polygon ARTRW with Native bunchgrass mix.
34	Degraded lava outcrop

Table 3. Morrison Ranch, Fort Rock Valley, OR.

Characteristics of Vegetation Associations and Juniper Treatment Prescriptions

Polygon	Acres	Juniper Phase	Post-settlement Juniper Stems/Ac.	Dominant Shrubs	Dominant Grasses	Juniper Treatment
35	12					5
36	29	early 2	50	ERNA	AGCR	3
37b	19	late 2/3	10	ERNA/ARTRW	FEID/AGCR	5
38	44	Pre	10	ARTRW/ERNA	Native Mix	5
39b	22	late 2/3	27	ARTRW/ERNA	Native Mix	5
40b	104	1	12	ERNA/CHVI	AGCR	1
41	39	Pre	10	ERNA/CHVI	Native Mix	5
42	99	1	<5	ERNA/CHVI	Native Mix	1
43	106	Pre	5	ERNA/CHVI	Native Mix	5
44	233	Pre	<5	ERNA/CHVI	Native Mix	5
45	140	Pre	25	ARTRW/ARTRT	Native Mix	4
46	30	2	17	ARTRW/ERNA	Native Mix	3
47	111	1	12	ARTRW/ERNA	Native/AGCR	2
48	34	Pre	<5	ERNA/ARTRW	Native/AGCR	4
49	48	1	15	ERNA/CHVI	AGCR	2
50	103	1	20	ERNA/ARTRW	AGCR	1
51	174	1	<5	ERNA/ARTRW	AGCR	1
52	20	1	15	ARTRW/ERNA	Native Mix	2
53	24	1	22	ARTRW/ERNA	FEID	2
54	7	1	20	ARTRW/ERNA	FEID	2
55	4	1	15	ARTRW/ERNA	Native Mix	2
56	28	1	15	ARTRW/ERNA	Native Mix	2
57	5	Pre	17	ERNA/ARTRW	Native Mix	5
58	50	Pre	17	ERNA/ARTRW	Native Mix	4
59	10	Pre	15	ERNA/ARTRW	Native Mix	5
60	179	Pre	5	ERNA/ARTRW	Native Mix	4
61	208	Pre	27	ARTRW/ERNA	Native Mix	4
62	46	early 2	17	ARTRW/ERNA	Native Mix	3
63	44	1	7	ARTRW/ERNA	Native Mix	2
64	27	early 2	55	ARTRW/ERNA	Native Mix	3

Shrub Abbreviations: ARTRT-basin big sagebrush, ARTRV-mountain big sagebrush, ARTRW- Wyoming big sagebrush, ERNA-Gray Rabbitbrush, CHVI-Green Rabbitbrush

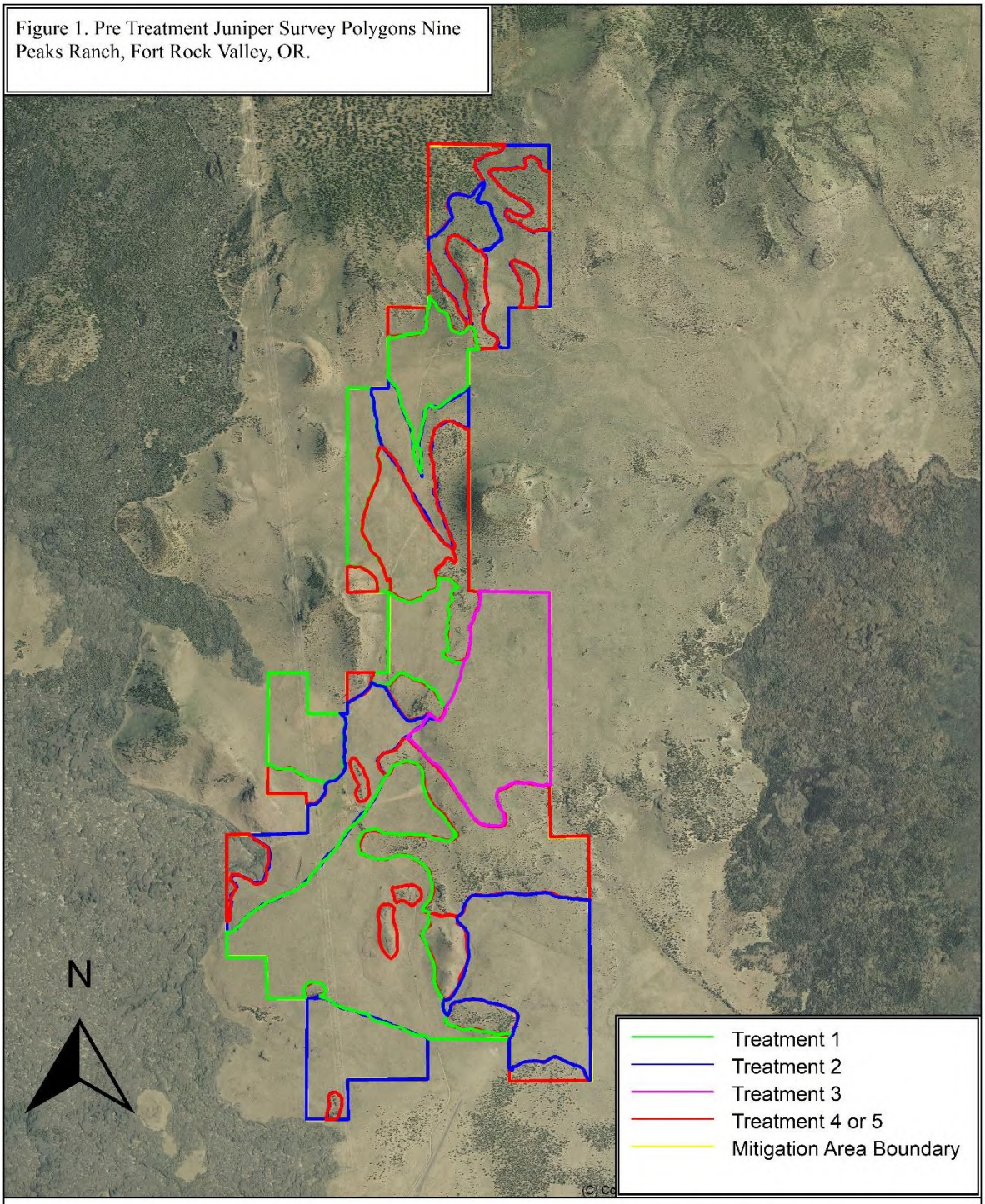
Grass Abbreviations: AGCR-crested wheatgrass, FEID-Idaho fescue

Species in Native Mix: Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, squirrel tail grass, Sandberg's bluegrass, Indian ricegrass

Table 4. Morrison Ranch, Fort Rock Valley, OR.
Vegetation Association Polygon Comments

Polygon	Comments
35	Cinder Pit
37b	Scattered pre-settlement throughout. Probably was a pre-settlement stand but ~ 100 years ago most trees cut - being replaced with older Post-settlement trees
	Polygon 37a is 22 acres
38	Post settlement trees are 10/ac of trees ~80 years old and <5/ac of trees ~20 years old
39b	Scattered pre-settlement throughout. Polygon 39a is 4 acres
40b	Juniper distribution patchy- large areas of <5 stems/ac. Polygon 40a is 60 acres.
41	Within winter feed lot. Shrubs very sparse.
42	Within winter feed lot. Shrubs very sparse.
43	Denser stand of Pre-settlement and old Post-settlement trees. JUOC <40 years are <5/ac.
	Within winter feed lot. Shrubs very sparse.
44	Sparse stand of pre-settlement. Post-settlement trees ~ 20 yrs old and <5/ac
45	A portion of the area west of the road was an old feed lot. In this area
	post settlement <5/ac. Shrubs CHNA/CHVI.
46	Scattered Pre-settlement throughout.
47	Scattered Pre-settlement throughout.
49	Scattered Pre-settlement throughout.
50	Old rye hay field converted to AGCR ~ 40 years ago
51	Old rye hay field converted to AGCR ~ 40 years ago
52	Ward Well #1 on tablet pictures
53	Shallow draw bottom between degrading lava flows. Ward Well #4 on tablet pictures
54	Shallow draw bottom between degrading lava flows.
55	Better soil inclusion in degraded lava flow
56	Shallow draw between degraded lava flows. Juniper density increases south to north
57	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
58	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
59	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
60	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
62	Scattered Pre-settlement throughout.
63	Scattered Pre-settlement throughout.
64	Scattered Pre-settlement throughout.

Figure 1. Pre Treatment Juniper Survey Polygons Nine Peaks Ranch, Fort Rock Valley, OR.

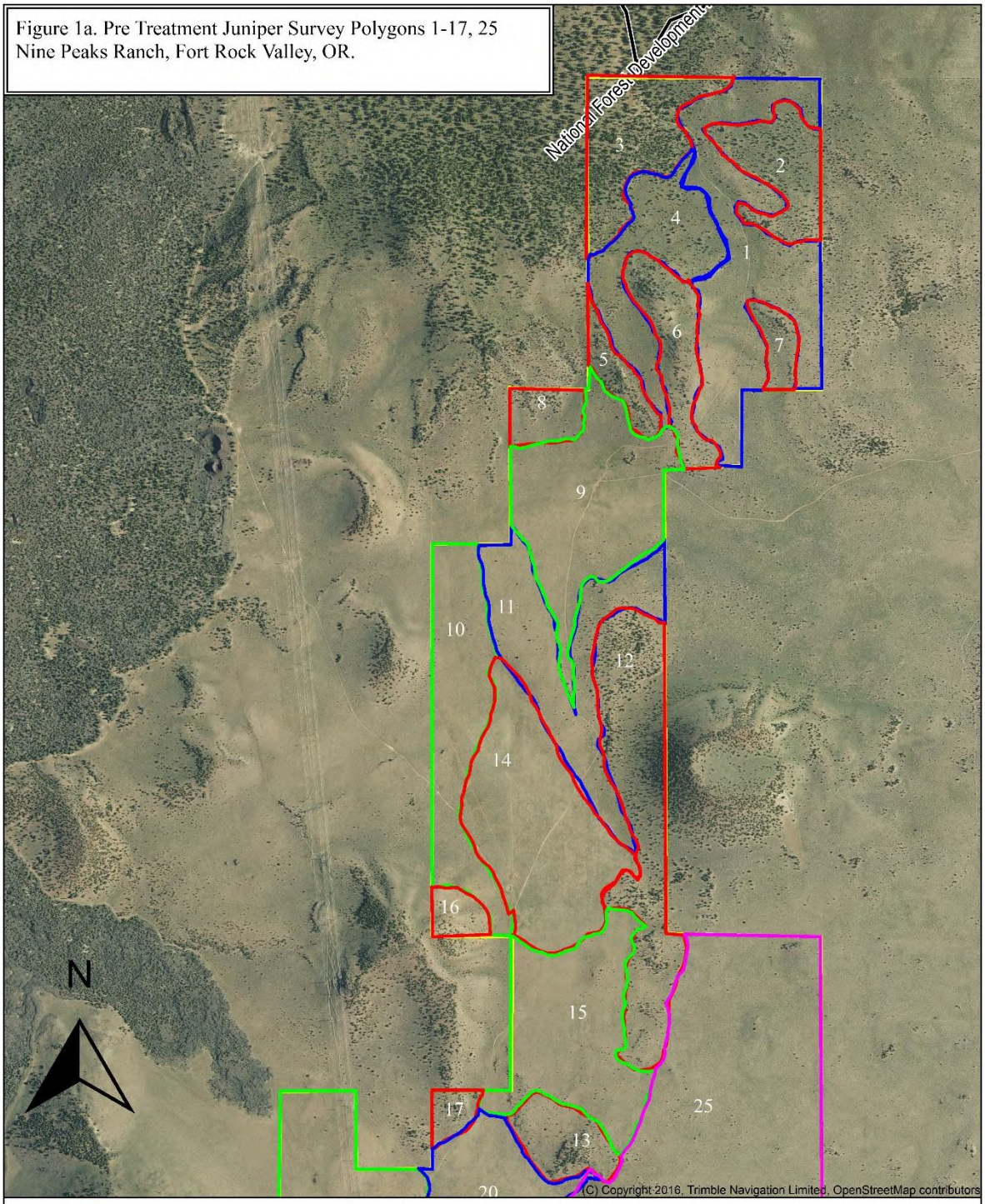


4595 acres
Date: 05/14/20
Scale: 1 inch = 4,000 ft.

Location: 10 0675379 E, 4817258 N
Fosters Natural Resource Contracting

(C) Copyright 2016, Trimble Navigation Limited

Figure 1a. Pre Treatment Juniper Survey Polygons 1-17, 25
Nine Peaks Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 2,083 ft.

Location: 10 0674197 E, 4819051 N
Fosters Natural Resource Contracting

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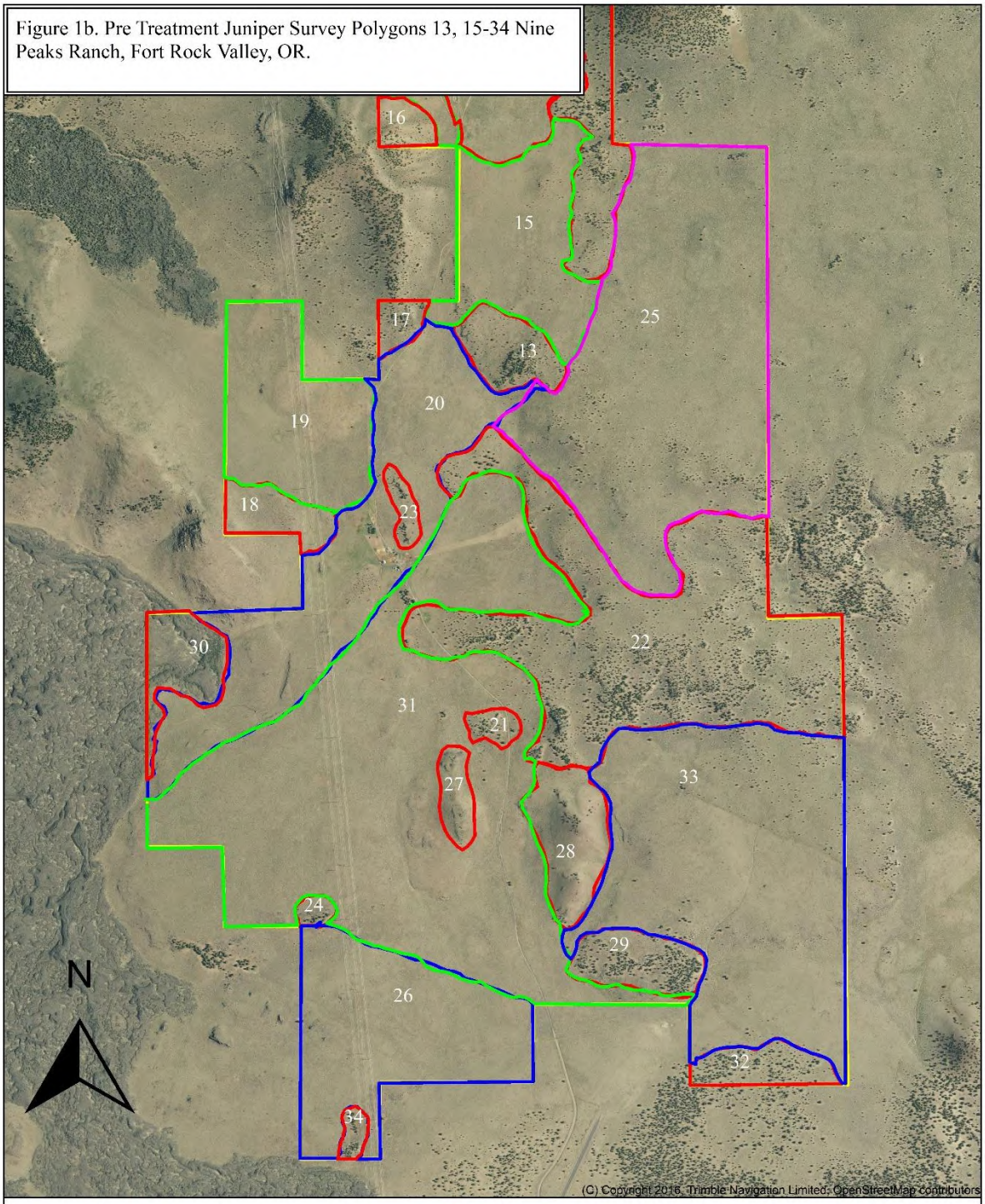
Figure 1b. Pre Treatment Juniper Survey Polygons 13, 15-34 Nine Peaks Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 2,083 ft.

Location: 10 0674581 E, 4814974 N
Fosters Natural Resource Contracting

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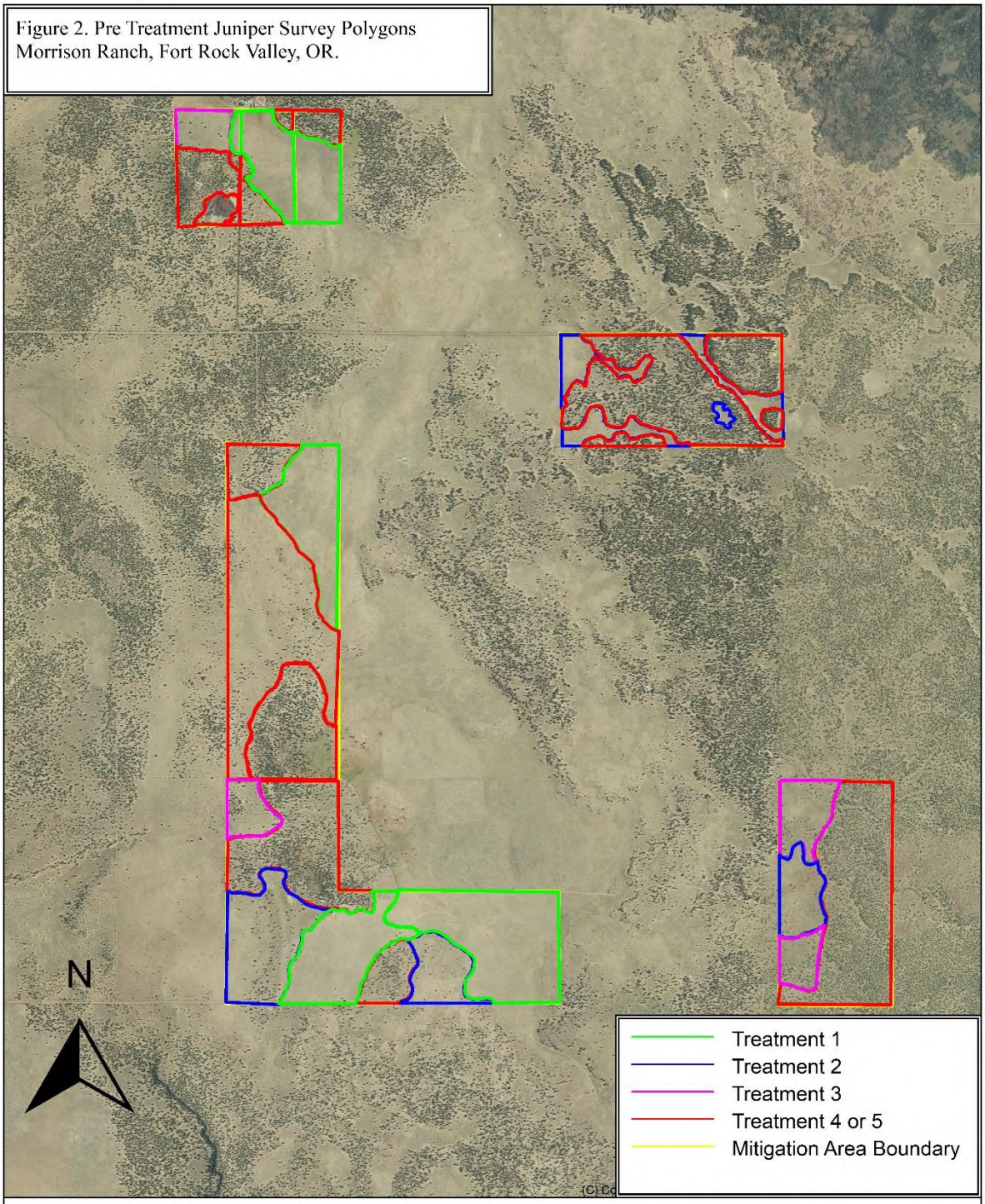
Figure 2. Pre Treatment Juniper Survey Polygons
Morrison Ranch, Fort Rock Valley, OR.



1939 acres
Date: 05/14/20
Scale: 1 inch = 2,916 ft.

Location: 10 0678120 E, 4807203 N
Fosters Natural Resource Contracting

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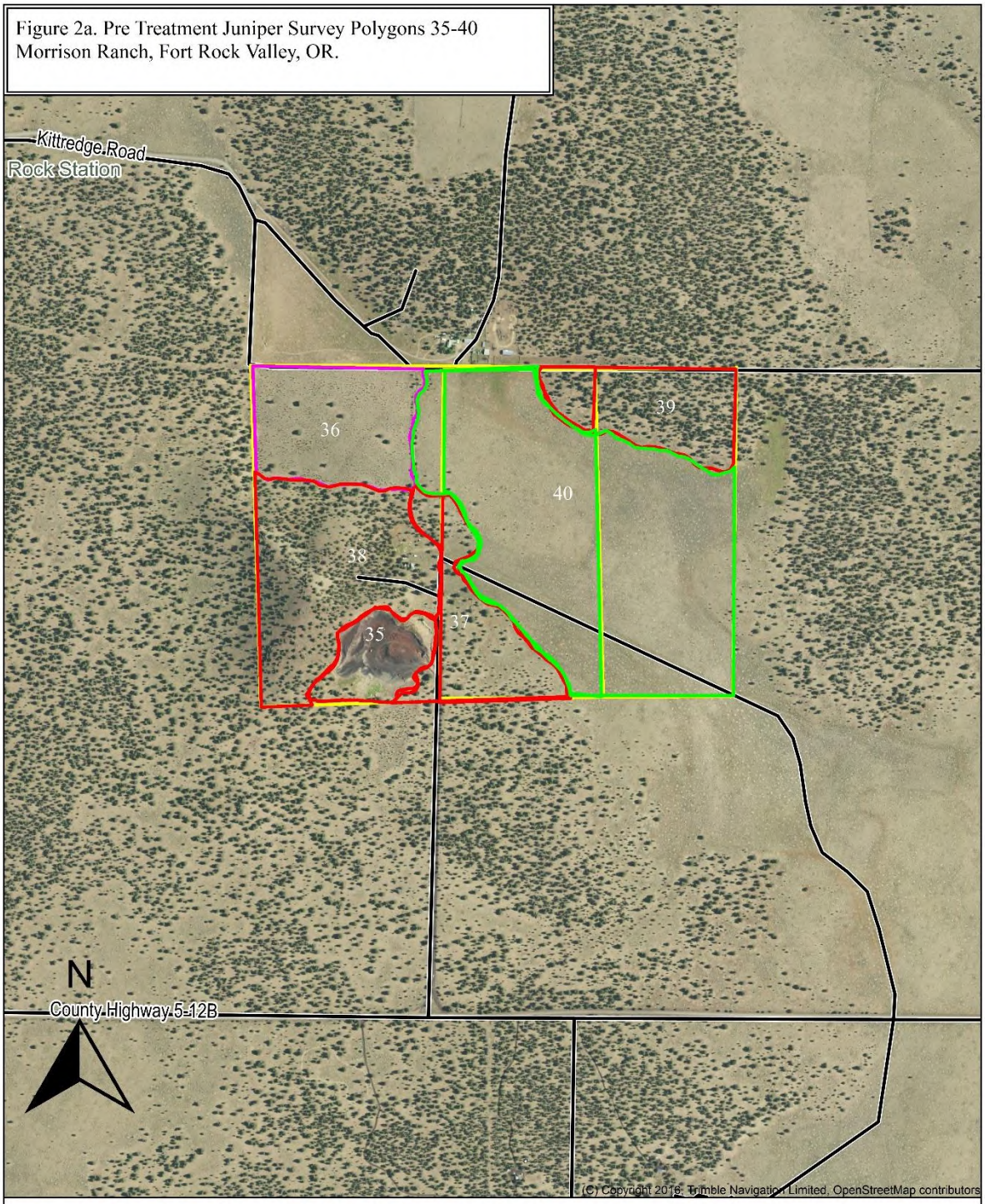
Figure 2a. Pre Treatment Juniper Survey Polygons 35-40
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0676334 E, 4810132 N
Fosters Natural Resource Contracting

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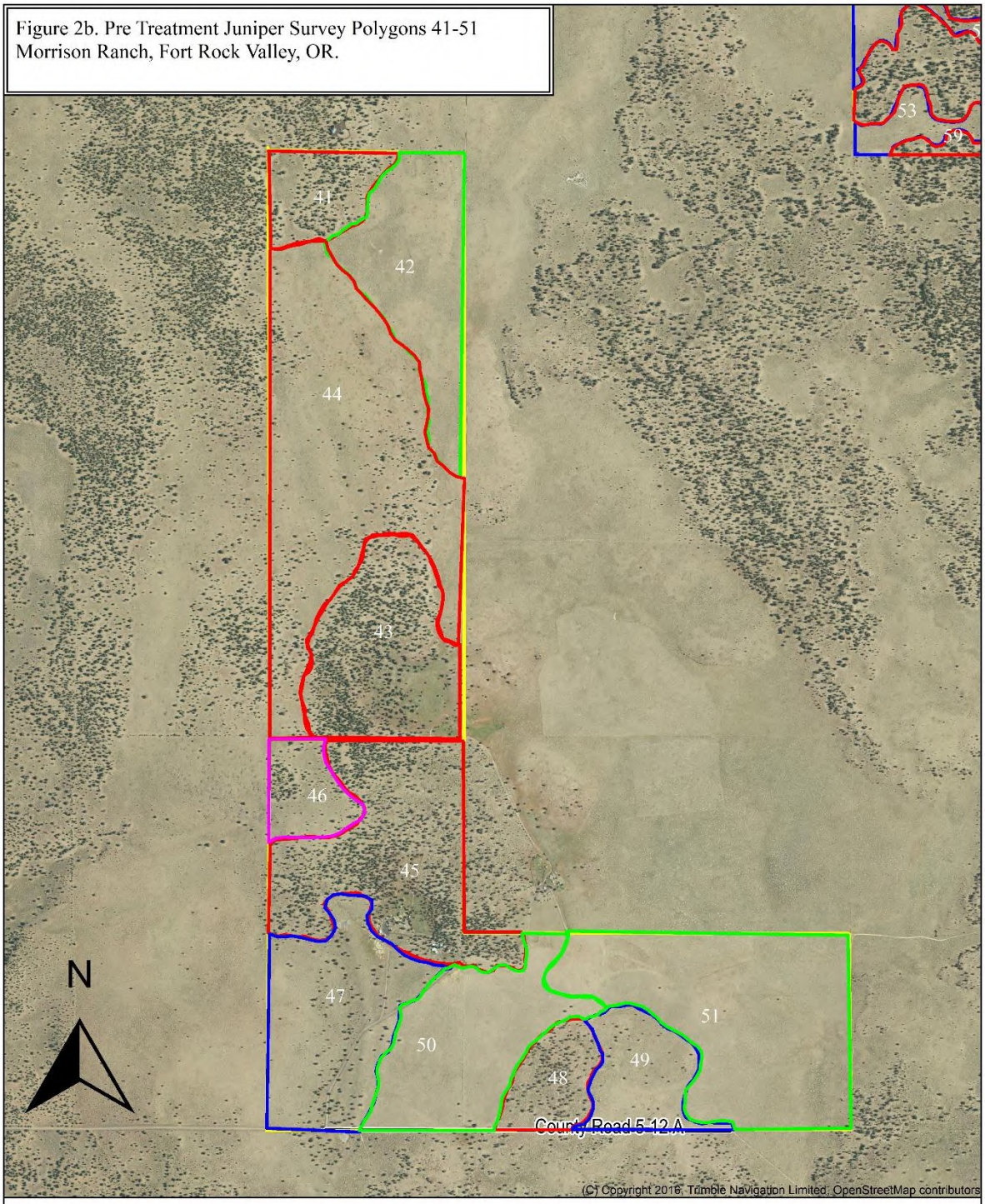
Figure 2b. Pre Treatment Juniper Survey Polygons 41-51
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,666 ft.

Location: 10 0677139 E, 4806452 N
Fosters Natural Resource Contracting

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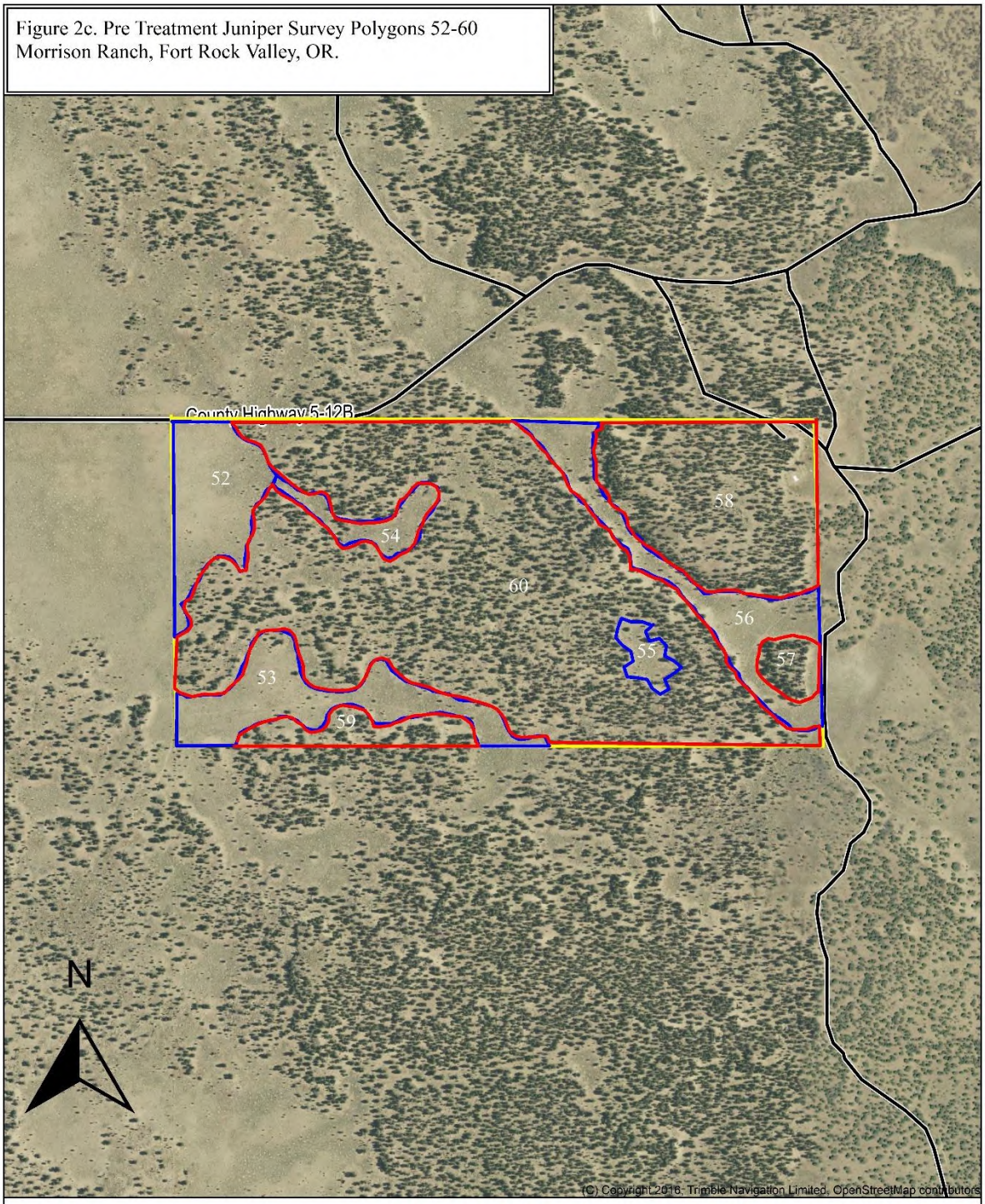
Figure 2c. Pre Treatment Juniper Survey Polygons 52-60
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0679375 E, 4808720 N
Fosters Natural Resource Contracting

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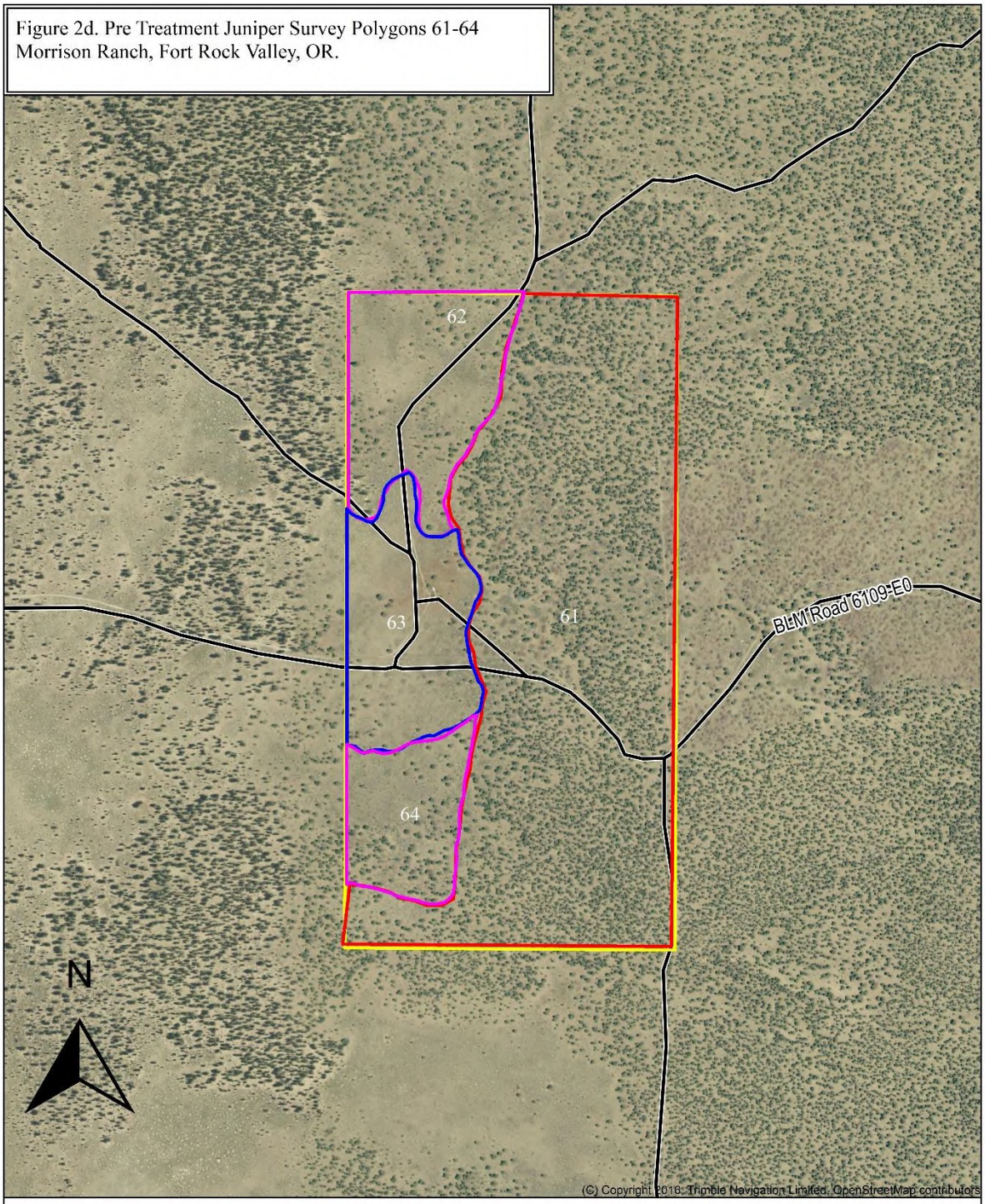
Figure 2d. Pre Treatment Juniper Survey Polygons 61-64
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0680626 E, 4805201 N
Fosters Natural Resource Contracting

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Figure 3. Older pre settlement and late post settlement juniper with open trunk, and young juniper less than 8 feet tall with live limbs to ground level. Morrison Ranch, Fort Rock Valley, OR. April, 2020.

Figure 4. Rock out crop with juniper Fort Rock Valley, OR. April 2020.

Treatment 1

Hand cut or pull and leave all juniper less than 5 feet tall. For juniper more than 5 feet tall, cut or pull, then lop and scatter limbs and trunks.

This treatment will be applied to phase 1 juniper stands (Figure 5). Polygons in Figures 1 and 2 with this treatment are outlined in green. Lop and scatter of slash from larger phase 1 trees serves two purposes. First it breaks dry fuel continuity. Second it reduces the potential for weed infestations due to smothering of understory vegetation by fine limbs and needles of cut juniper (Bates and Svejcar, 2009).

Figure 5. Low density phase 1 juniper. Treatment 1. Fort Rock Valley, OR, April, 2020.

Treatment 2

Hand cut or pull and leave all juniper less than 5 feet tall. Juniper over 5 feet tall will be cut or pulled and the slash will be piled and covered. Piles will be burned 12 to 24 months after piling during the winter or early spring when soils are either frozen or saturated from melting winter snow. The timing of the burn is important to reduce the chance of fire spreading to understory vegetation surrounding the piles. Seed the burned spots with a grass/legume mix after the fires are out but within 30 days after pile burning.

This treatment will be applied to phase 1 stands with higher juniper densities and early phase 2 stands (Figure 6). Polygons in Figures 1 and 2 with this treatment are outlined in blue. The purpose of covering piles is to keep the center of the pile dry which improves consumption of the slash and lengthens the burn window when piles can be effectively ignited. Covers need to be made of waterproof material, approximately 4 feet X 4 feet and placed on top of the piles then held down by other pieces of slash so they don't blow away.

Figure 6. Higher density early phase 2 juniper. Ponderosa pine will not be cut. Treatment 2. Fort Rock Valley, OR, April, 2020.

Treatment 3

Cut or pull juniper then pile and cover the slash. See treatment 2 for timing of pile burning and seeding.

This treatment will be applied to phase 2 and early phase 2 stands with juniper dense enough that using treatments 1 or 2 would result in excessive fuel loading or impact animal movement and understory recruitment (Figure 7). Polygons in Figures 1 and 2 with this treatment are outlined in magenta. See treatment 2 for purpose and description of covering slash.

Figure 7. Phase 2 juniper. Treatment 3. Fort Rock Valley, OR, April, 2020.

Treatment 4

Hand cut juniper that have closed trunks (i.e. live limbs to ground level) and are less than 8 feet tall. Pile slash in openings making an effort to minimize fire effect to live juniper retained in the stand. Cover piles and seed blackened areas after pile burning. See treatment 2 for timing of pile burning and seeding, and purpose of covering slash piles. In order to protect the lava structure common to several of the pre-settlement stands on the Morrison Ranch young juniper should not be pulled and piled using machinery, rather juniper should be hand cut and piled.

The purpose of this treatment is to break fuel continuity in pre-settlement stands (Figure 8). Polygons in Figures 1 and 2 with this treatment are outlined in red. The purpose of this treatment is to protect pre-settlement juniper stands from the effect of wildfire by breaking fuel connectivity. It is intended to protect the big game cover values provided by the stand as well as the intrinsic value of the pre-settlement juniper.

Figure 8. Pre-settlement juniper with young juniper. Treatment 4. Fort Rock Valley, OR, April, 2020.

Treatment 5

No juniper treatment. Polygons in Figures 1 and 2 with this treatment are outlined in red. The reason for selecting this treatment varied. 1.) Some polygons had no juniper (e.g. polygon 14, figure 1a). 2.) Young post settlement juniper targeted in treatment 4 were not dense enough in cover polygons to warrant treatment (e.g. polygon 43, figure 2b). 3.) The prescription for the polygon was to recruit juniper in order to provide future cover (Polygon 18, figure1b). 4.) Most of the soil substrate within the polygon is rock outcrop or degraded lava, the presence of which will protect the stand from all but the most severe wildfire event (polygon 57 figure 2c).

Cost Estimate

Table 5 presents estimated costs for the treatments identified in tables 1 and 3. These estimates were determined using 2020 costs for similar juniper treatment projects in Lake County.

Table 5. Estimated cost of juniper treatment selected on Obsidian Solar Center Mitigation Properties in the Fort Rock Valley, Oregon using 2020 average prices for similar treatments in Lake County Oregon.

	Nine Peaks Ranch (acres)	Morrison Ranch (acres)[a]	Estimated[b] (cost/acre)	Estimated Total (cost/acre)
Treatment 1	1342	480	$ 30	$ 54,660
Treatment 2	1375	286	$ 110	$ 182,710
Treatment 3	499	132	$ 280	$ 176,680
Treatment 4	46	611	$ 160	$ 105,120
Treatment 5	1331	490	0	$ -
Total	4593	1999		$ 519,170

[a] acres on Morrison ranch will decrease by ~ 60 acres when location of cinder pit parcel is determined

[b] cost includes cost of juniper treatment plus $10/ac (treatments 2 and 4) or $20/ac (treatment 3) for seeding

Weed Management

As noted in the pre-treatment juniper field survey (Appendix 1) no noxious weed infestations were found on either mitigation property. There is potential to cause establishment of noxious weeds through the ground disturbing activities of juniper treatment. The following best management practices will be used to guard against introducing noxious weeds to the mitigation properties:

1. All equipment used for juniper treatment will be required to be cleaned at an approved weed wash out station immediately prior to starting mitigation treatments. If the equipment is removed from the treatment area to work at another location it will be cleaned again immediately prior to continuing juniper treatments.

2. As stated in the juniper treatment descriptions all pile areas burned for slash treatment will be reseeded with a grass/legume mix after the fires have gone out but within 30 days of the piles being burned.

3. Monitor the burned areas for noxious weed establishment annually for 3 years following reseeding. If noxious weeds are detected work within the weed contract already established with the Lake County Cooperative Weed Management Area to effectively treat the infestation.

Monitoring

Monitoring is designed to measure that juniper treatments in forage polygons were successful at removing the effect of juniper encroachment on understory vegetation; and that treatments, or no treatment in cover polygons, was successful and maintaining cover quality for wintering big game.

At least one permanent photo point will be randomly selected in each polygon (Barrett 2007). Polygons larger than 200 acres will have 2 permanent photo points established. The polygons with 2 photo points will be stratified so that one point is in the northern 1/3rd of the polygon and one is in the southern 1/3rd. The three transect layout suggested by Barrett (2007) will be modified so each transect is 100 X 20 yards (0.4 acres) and in addition to qualitative monitoring of understory vegetation using photos, all juniper within the transect will be counted to measure juniper density pre and post treatment.

Because mitigation treatments will be implemented on a rolling schedule, which is tied to the rolling schedule of solar development, monitoring will occur as the polygons are scheduled for treatment. Establishment of photo points and pretreatment monitoring will be completed within 6 months prior to a polygon being scheduled for treatment. The first post treatment monitoring will occur within 1 year after treatment is completed. Polygons within which no treatment is planned (Treatment 5) will be monitored when neighboring polygons with a common boundary are scheduled for treatment. Each photo point and associated transects will be re-monitored every 10 years after completion of the first post treatment monitoring for the life of the project.

Maintenance

Because juniper will be left in most of the polygons, some amount of juniper encroachment will occur in the forage polygons within the life of the Facility. When the results of monitoring indicate that juniper encroachment has exceeded 10 stems/acre over a majority of a polygon then encroaching juniper will be cut using treatment 1. This maintenance commitment is for the duration of the Facility life pursuant to the HMP.

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Appendix 1

Pre-Treatment Juniper Field Survey Report

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Introduction

Obsidian Solar Center LLC (Obsidian) is applying for a site certificate from the Oregon Energy Facilities Siting Council (EFSC) to build and operate the Obsidian Solar Facility in the Fort Rock Valley of Lake County, Oregon (Facility). A condition of the site certificate will require Obsidian to mitigate for the Facility's impacts to Category 2 big game winter range habitat. Obsidian has developed a Habitat Mitigation Plan (HMP). The HMP proposes to establish a Working Lands Improvement Program (WLIP) on portions of two properties, totaling 6,534 acres in the Fort Rock Valley (HMP Attachment 3). The total acreage enrolled in the WLIP will depend on the permanent footprint from the Facility's final design. The WLIP is two-fold: it involves habitat protection under a WLIP landowner agreement, and big game winter habitat enhancement using a juniper treatment program. The HMP identifies 5 steps to implement the juniper treatment and management program (HMP Section 3.3, page 8). Steps 1 and 2 involves completing a pre-treatment juniper (*Juniperus occidentalis*) field survey and developing a juniper treatment plan for the two properties. The purpose of this document is to present results of the juniper field survey (Step 1).

The goal of the WLIP is to provide mitigation by maintaining and improving big game winter habitat on the mitigation properties. Winter range will be maintained by establishing a WLIP agreement with the landowners. Big game winter range will be improved by providing a mosaic of vegetation associations designed to provide big game cover and forage areas across the properties. Juniper encroachment into shrub steppe habitats results in reduced forage quality and quantity due its ability to out compete shrubs and bunchgrass (Vaitkas and Eddleman 1987, Miller and Rose 1999, Miller et al. 2005, Davies et al. 2011). Forest vegetation associations are an important habitat component for wintering big game as they provide both thermal and hiding cover (Leckenby and Adams 1986, Boyce et al. 2003, Coe et al. 2018). Juniper woodlands are the primary forest habitat available during winter in the Fort Rock Valley (Coe et al. 2018). Therefore, actions under the HMP are not designed to just cut juniper, but are intended to provide quality winter habitat on the properties.

Pre-Treatment Juniper Survey

Juniper surveys were completed during the first 2 weeks of April and the second week of May, 2020 using the Obsidian habitat assessment protocol (Appendix 1) approved by Oregon Department of Energy (ODOE) in consultation with Oregon Department of Fish and Wildlife

(ODFW). As directed in the habitat assessment protocol field surveys for noxious weeds were conducted while completing the juniper surveys.

Nine Peaks Ranch

Field surveys were conducted on approximately 4,595 acres in a single parcel of the Nine Peaks Ranch. Results of the juniper survey are presented in Tables 1 and 2, and Figures 1, 1a and 1b. Juniper densities shown in Table 1 were measured using one or more 100 yard X 20 yard (0.4 acre) transects per vegetation association polygon.

Soils are generally sandy to ashy loams with varying amounts of rock. Rock ranges from none in areas with gentle slopes to ridges with significant cobble or large stone. Basalt outcrops and degraded lava flows are common. Average annual precipitation is 12 inches, most of which falls as snow in the winter. The Nine Peaks parcel lies within the Paulina wildlife management unit (WMU) on big game winter range designated in the Lake County Comprehensive Land Use Plan. In addition to its importance as winter range, the Nine Peaks property is located between the Devils Garden and East Lava Field and is a significant migration corridor for mule deer moving to and from other winter areas in the Paulina and Fort Rock WMUs (Coe et. al, 2018).

The property has been managed as a working livestock operation since at least the early 1900's. Valley bottoms with sandy or ashy loam soils were converted to rye (*Secale cereale*) hay fields, then in the 1970's or 1980's those fields were seeded to crested wheatgrass (*Agropyron cristatum*). Gray rabbitbrush (*Ericameria nauseosus*) has established in the crested wheatgrass seedings. Cattle are grazed using a rest rotation system.

Past management actions or wildfire have resulted in most of the juniper stands on sandy to ashy loam soils being in phase 1 or early phase 2 condition. Pre-settlement or mixed pre-settlement/late phase 2-phase 3 stands are common and occur on cobble to rocky soils, degraded lava eruptions or rock outcrops.

Elevations range from 5200 feet on the north end of the property to 4500 feet on the south, with the majority of the property being below 4900 feet. Areas above 5000 feet elevation are ponderosa pine (*Pinus ponderosa*) forest stands with a bitterbrush (*Purshia tridentata*)/ Idaho fescue (*Festuca idahoensis*) understory. Between 5000 and 4900 feet, ponderosa pine and juniper are codominant, shrubs are bitterbrush and mountain big sagebrush (*Artemesia tridentata vasyeana*), and Idaho fescue is the dominant grass. Below 4900 feet vegetation associations are variable with areas not converted to crested wheatgrass dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) and gray rabbitbrush with a mix of native bunchgrass including: Idaho fescue, blue bunch wheatgrass (*Pseudoroegneria spicatum)*, Thurbers needlegrass (*Achnatherum thurberianum*), Indian rice grass (*Achnatherum hymenoides*), squirrel tail grass (*Elymus elymoides*) and Sandberg's blue grass (*Poa sandbergii*).

No weed species of concern (Table 1, Attachment 2) were found on either property. Cheatgrass (*Bromus tectorum*), is widely distributed across both properties. Tumble mustard (*Sysimbrium altissimum*) and tansy mustard (*Descurania spp.*) are common in disturbed sites. Although these species are non-native and invasive, they are widely naturalized throughout North America and should not be a specific target of weed control on big game winter range.

Table 1. Nine Peaks Ranch, Fort Rock Valley, OR

Characteristics of Vegetation Association Polygons Deliniated during Pre-treatment Juniper Suvey

Polygon	Acres	Juniper Phase	Post-settlement Juniper Stems/Ac.	Dominant Shrubs	Dominant Grasses
1	183	PIPO/JUOC	22	PUTR/ARTRV	FEID
2	61	PIPO/JUOC	27	PUTR/ARTRV	FEID
3	87	PIPO	<5	PUTR/ARTRV	FEID
4	92	1	17	ARTRW/PUTR	FEID
5	24	2	75	ARTRW/PUTR	FEID
6	58	2	27	ARTRW/PUTR	FEID
7	18	2	37	ARTRW/PUTR	FEID
8	26	late 2	40	ARTRW/ERNA	Native Mix
9	162	1	<5	ARTRW/ERNA	Native Mix
10	120	1	<5	ARTRW/ERNA	Native Mix
11	132	1/early2	10 W, 20E	ARTRW/ERNA	Native Mix
12	156	2	50	ARTRW/ERNA	Native Mix
13	42	late 2	40	ARTRW/ERNA	Native /AGCR
14	177	none	0	ERNA/CHVI	Native Mix
15	149	1	20	ARTRW/ERNA	Native /AGCR
16	16	2	42	ARTRW	Native Mix
17	14	2	40	ARTRW	Native Mix
18	32	early 2	30	ARTRW	Native Mix
19	154	1	<5	ERNA/CHVI	Native /AGCR
20	296	1	7	ERNA/ARTRW	Native /AGCR
21	11	2	32	ARTRW	Native Mix
22	420	2	60	ARTRW	Native Mix
23	11	Pre	10	ARTRW	Native Mix
24	7	Pre	10	ARTRW	Native Mix
25	499	1/early 2	25	ARTRW	Native Mix
26	221	1	10	ERNA/ARTRW	Native /AGCR
27	19	1	10	ARTRW/ERNA	Native Mix
28	63	1	10	ARTRW/ERNA	Native Mix
29	46	Pre	35	ARTRW	Native Mix
30	47	Lava	35	ARTRW	Native Mix
31	757	1	10	ERNA/ARTRW	Native /AGCR
32	34	2	52	ARTRW/ERNA	Native Mix
33	451	early 2	17	ARTRW/ERNA	Native /AGCR
34	8	Pre	10	ARTRW	Native Mix

Shrub Abbreviations: ARTRT-basin big sagebrush, ARTRV-mountain big sagebrush, ARTRW- Wyoming big sagebrush, ERNA-Gray Rabbitbrush, CHVI-Green Rabbitbrush, PUTR-bitterbrush

Grass Abbreviations: AGCR-crested wheatgrass, FEID-Idaho fescue

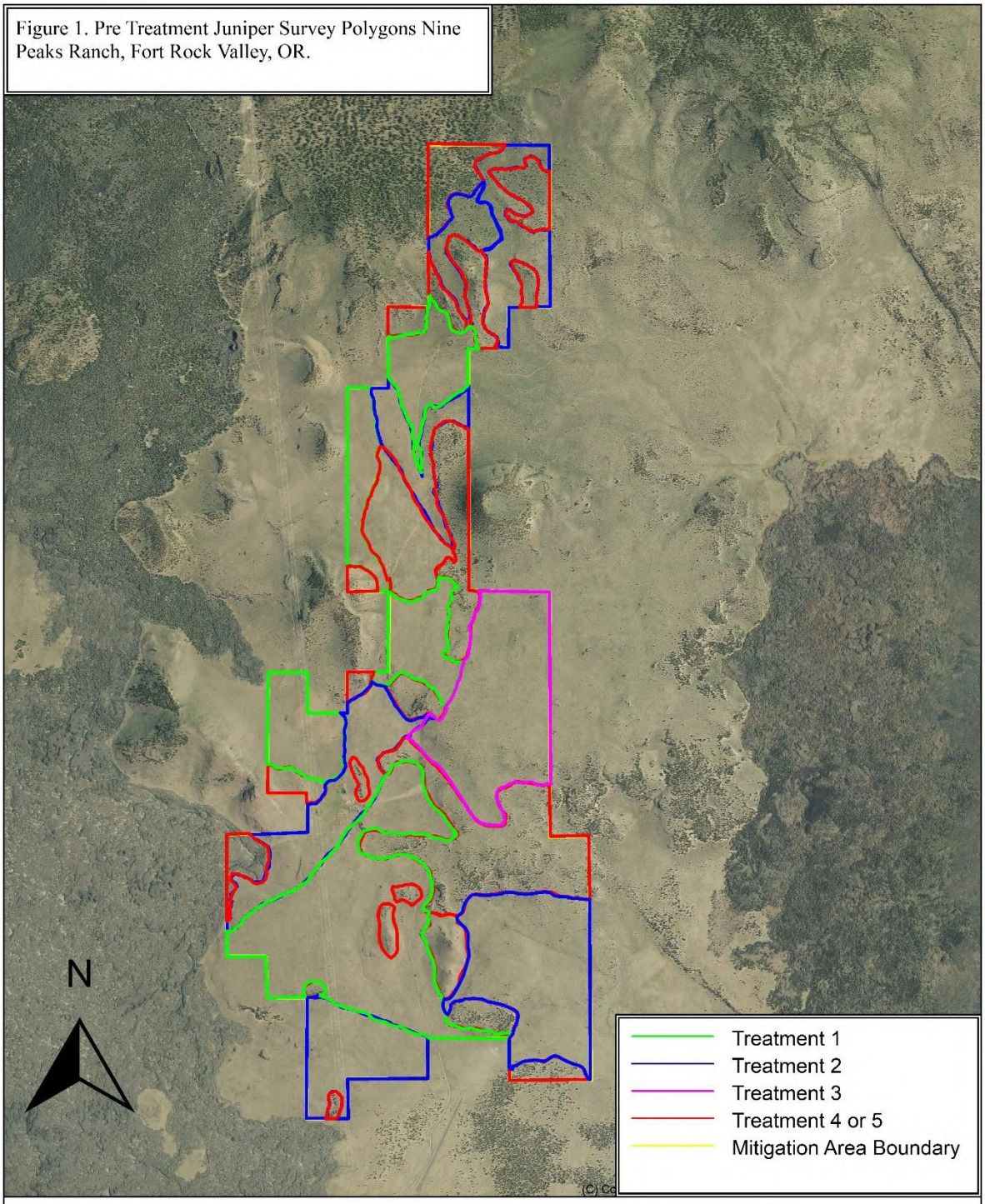
Species in Native Mix: Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, squirrel tail grass, Sandberg's bluegrass, Indian ricegrass

Table 2. Nine Peaks Ranch, Fort Rock Valley, OR

Vegetation Association Polygon Comments

Polygon	Comments
1	Juniper mixed with PIPO - PIPO density decreases going south
2	Juniper codominant with PIPO - substantial number of older trees both species
3	PIPO stand with a few juniper
4	Open JUOC/PIPO codominant stand
5	Rocky ridge
6	Scattered pre-settlement juniper on rock out crops
7	Scattered pre-settlement juniper on rock out crops
11	West leg of polygon has 10 stems/ac; East leg has 20 stems/ac
12	Juniper distribution patchy. Pockets of late 2 and pre-settlement
13	Mixed pre and older post settlement on very rocky soils
17	Rock out crops with scattered pre-settlement
18	Variable juniper density, leave for cover recruitment
20	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
21	Phase 3 on rock out crops
22	Pre-settlement or late phase 2/phase 3 on rock outcrops
	Areas of better soil have early phase 2 juniper @ 25 stems/ac
23	Degraded lava outcrop
24	Degraded lava outcrop
25	Pockets of phase 1 throughout with ~10 stems/ac
26	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
27	Most of polygon burned in wildfire. Shrubs limited
28	Most of polygon burned in wildfire. Pre-settlement remains on rock outcrops
29	Swath on west end that was chained years ago phase 2 with CHNA/ARTRW
30	Aspen clone on east end with very little juniper in aspen
31	Areas with better soil converted to AGCR with CHNA encroaching
	Areas with rocky soils are ARTRW with Native Mix
32	Pre-Settlement JUOC scattered throughout
33	Flatter areas chained years ago and seeded to AGCR, CHNA encroaching
	Remainder of polygon ARTRW with Native bunchgrass mix.
34	Degraded lava outcrop

Figure 1. Pre Treatment Juniper Survey Polygons Nine Peaks Ranch, Fort Rock Valley, OR.



4595 acres
Date: 05/14/20
Scale: 1 inch = 4,000 ft.

Location: 10 0675379 E, 4817258 N
Fosters Natural Resource Contracting

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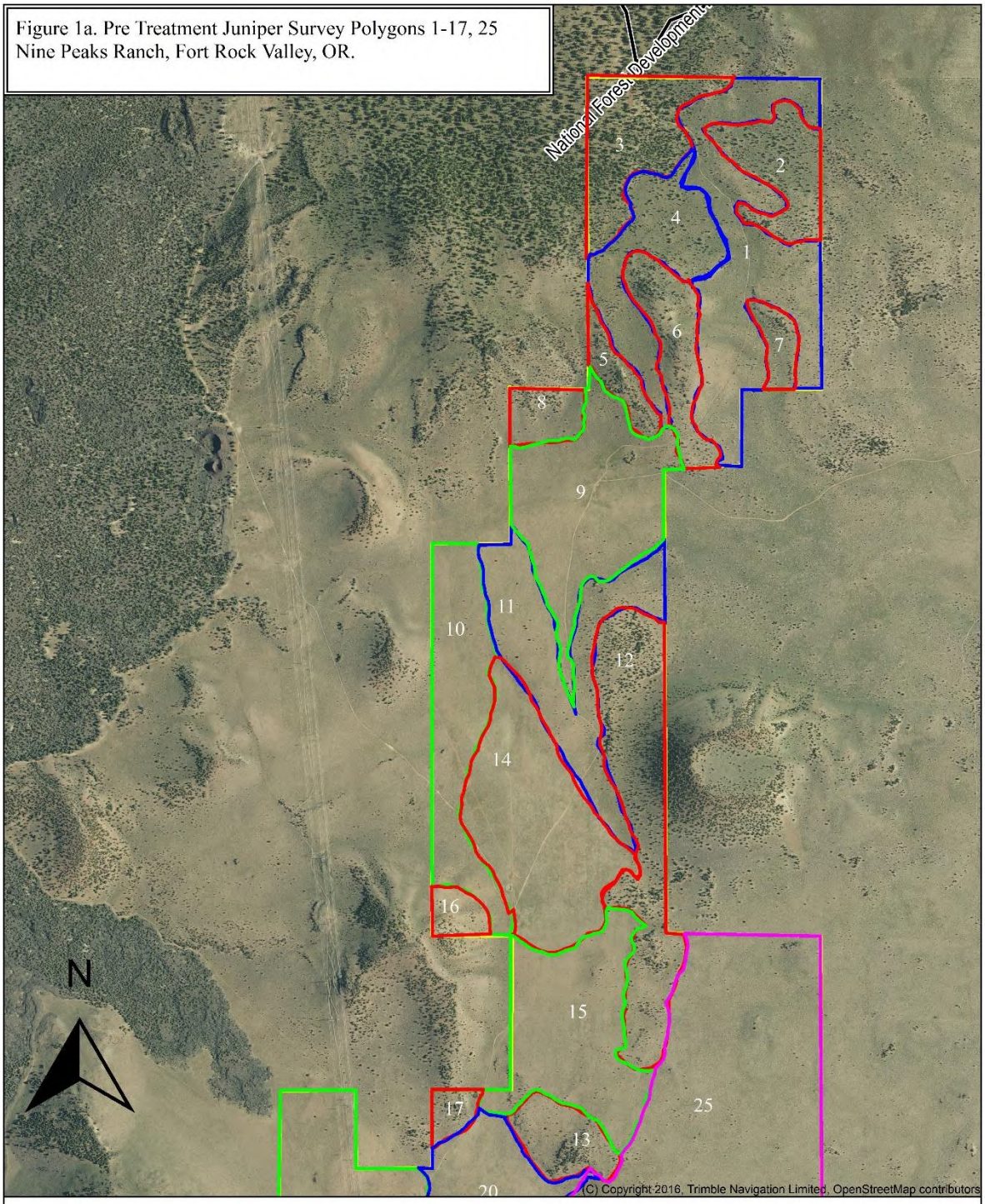
Figure 1a. Pre Treatment Juniper Survey Polygons 1-17, 25
Nine Peaks Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 2,083 ft.

Location: 10 0674197 E, 4819051 N
Fosters Natural Resource Contracting

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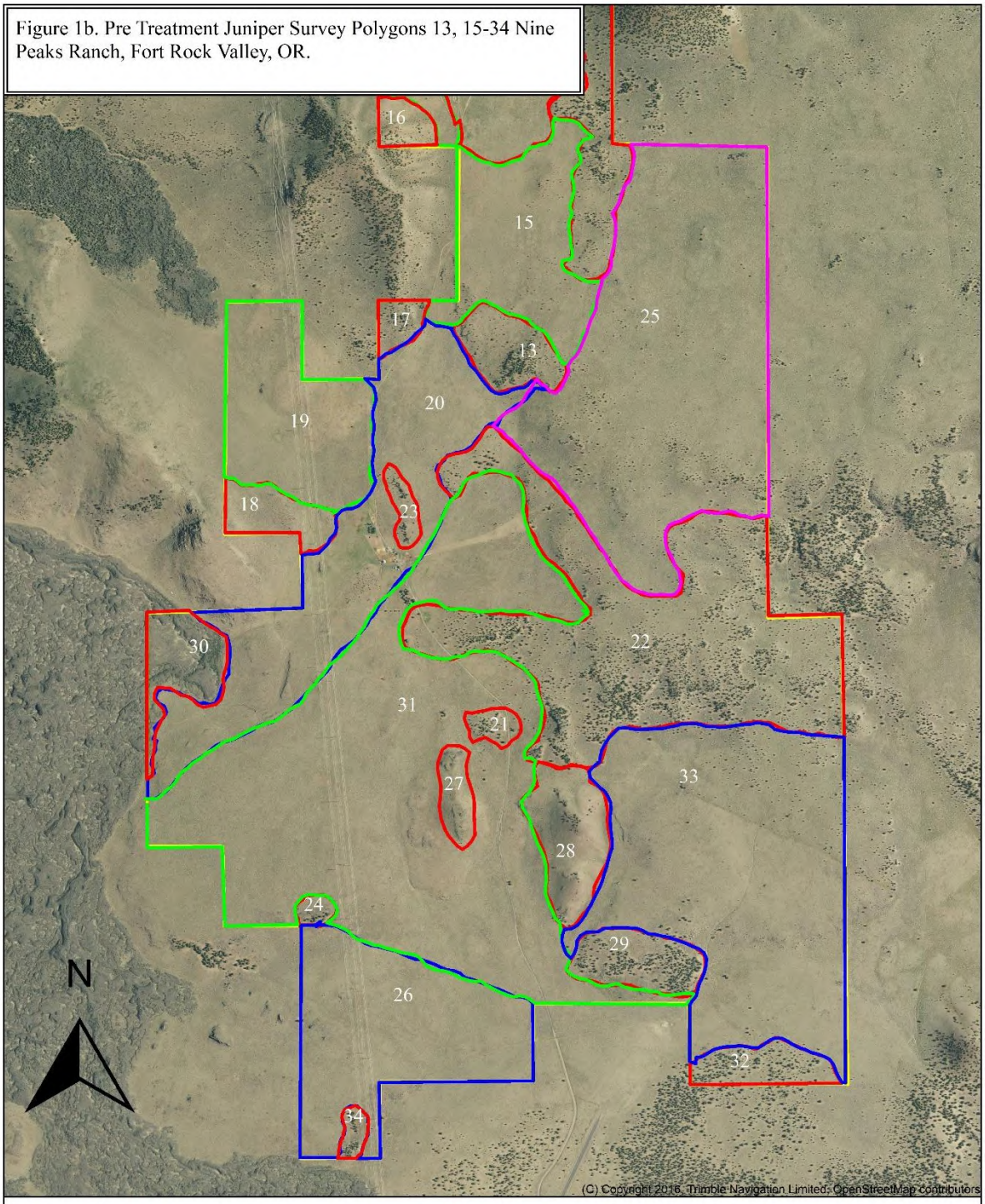
Figure 1b. Pre Treatment Juniper Survey Polygons 13, 15-34 Nine Peaks Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 2,083 ft.

Location: 10 0674581 E, 4814974 N
Fosters Natural Resource Contracting

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Morrison Ranch

Field surveys were completed on approximately 1,939 acres in four parcels of the Morrison ranch. Results of the juniper survey are presented in Tables 3 and 4, and Figures 2 and 2a-d. Juniper densities shown in Table 3 were measured using one or more 100 yard X 20 yard (0.4 acre) transects per vegetation association polygon.

Soils are generally sandy to ashy loams with varying amounts of rock. Basalt outcrops and degraded lava flows make up a larger proportion of the Morrison mitigation area than are found on Nine Peaks Ranch. Average annual precipitation is 12 inches, most of which falls as snow in the winter. The Morrison parcels lie within the Paulina wildlife management unit (WMU) on big game winter range designated in the Lake County Comprehensive Land Use Plan.

The property has been managed as a working livestock operation since at least the early 1900's. Valley bottoms with sandy or ashy loam soils were converted to rye (*Secale cereale*) hay fields, then in the 1970's or 1980's those fields were seeded to crested wheatgrass (*Agropyron cristatum*). Gray rabbitbrush (*Ericameria nauseosus*) has established in the crested wheatgrass seedings. Cattle are grazed using a rest rotation system with the exception of the area made up of polygons 41 through 44 (Figure 2b). This area is used as a winter feed area for cattle.

Past management actions or wildfire have resulted in most of the juniper stands on sandy to ashy loam soils being in phase 1 or early phase 2 condition. Pre-settlement or mixed pre-settlement/late phase 2-phase 3 stands are common and occur on degraded lava flows or rock outcrops.

Elevations range from 4750 to 4450 feet. Dominant shrubs are Wyoming big sagebrush and gray rabbitbrush. Native bunch grasses are Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, Indian rice grass, squirrel tail grass and Sandberg's blue grass. Individual pre-settlement juniper is scattered throughout all vegetation associations that have not been converted to crested wheatgrass.

No weed species of concern (Table 1, Attachment 2) were found on either property. Cheatgrass (*Bromus tectorum*), is widely distributed across both properties. Tumble mustard (*Sysimbrium altissimum*) and tansy mustard (*Descurania spp.*) are common in disturbed sites. Although these species are non-native and invasive, they are widely naturalized throughout North America and should not be a specific target of weed control on big game winter range.

Table 3. Morrison Ranch, Fort Rock Valley, OR.

Characteristics of Vegetation Association Polygons Deliniated during Pre-treatment Juniper Suvey

Polygon	Acres	Juniper Phase	Post-settlement Juniper Stems/Ac.	Dominant Shrubs	Dominant Grasses
35	12				
36	29	early 2	50	ERNA	AGCR
37b	19	late 2/3	10	ERNA/ARTRW	FEID/AGCR
38	44	Pre	10	ARTRW/ERNA	Native Mix
39b	22	late 2/3	27	ARTRW/ERNA	Native Mix
40b	104	1	12	ERNA/CHVI	AGCR
41	39	Pre	10	ERNA/CHVI	Native Mix
42	99	1	<5	ERNA/CHVI	Native Mix
43	106	Pre	5	ERNA/CHVI	Native Mix
44	233	Pre	<5	ERNA/CHVI	Native Mix
45	140	Pre	25	ARTRW/ARTRT	Native Mix
46	30	2	17	ARTRW/ERNA	Native Mix
47	111	1	12	ARTRW/ERNA	Native/AGCR
48	34	Pre	<5	ERNA/ARTRW	Native/AGCR
49	48	1	15	ERNA/CHVI	AGCR
50	103	1	20	ERNA/ARTRW	AGCR
51	174	1	<5	ERNA/ARTRW	AGCR
52	20	1	15	ARTRW/ERNA	Native Mix
53	24	1	22	ARTRW/ERNA	FEID
54	7	1	20	ARTRW/ERNA	FEID
55	4	1	15	ARTRW/ERNA	Native Mix
56	28	1	15	ARTRW/ERNA	Native Mix
57	5	Pre	17	ERNA/ARTRW	Native Mix
58	50	Pre	17	ERNA/ARTRW	Native Mix
59	10	Pre	15	ERNA/ARTRW	Native Mix
60	179	Pre	5	ERNA/ARTRW	Native Mix
61	208	Pre	27	ARTRW/ERNA	Native Mix
62	46	early 2	17	ARTRW/ERNA	Native Mix
63	44	1	7	ARTRW/ERNA	Native Mix
64	27	early 2	55	ARTRW/ERNA	Native Mix

Shrub Abbreviations: ARTRT-basin big sagebrush, ARTRV-mountain big sagebrush, ARTRW- Wyoming big sagebrush, ERNA-Gray Rabbitbrush, CHVI-Green Rabbitbrush

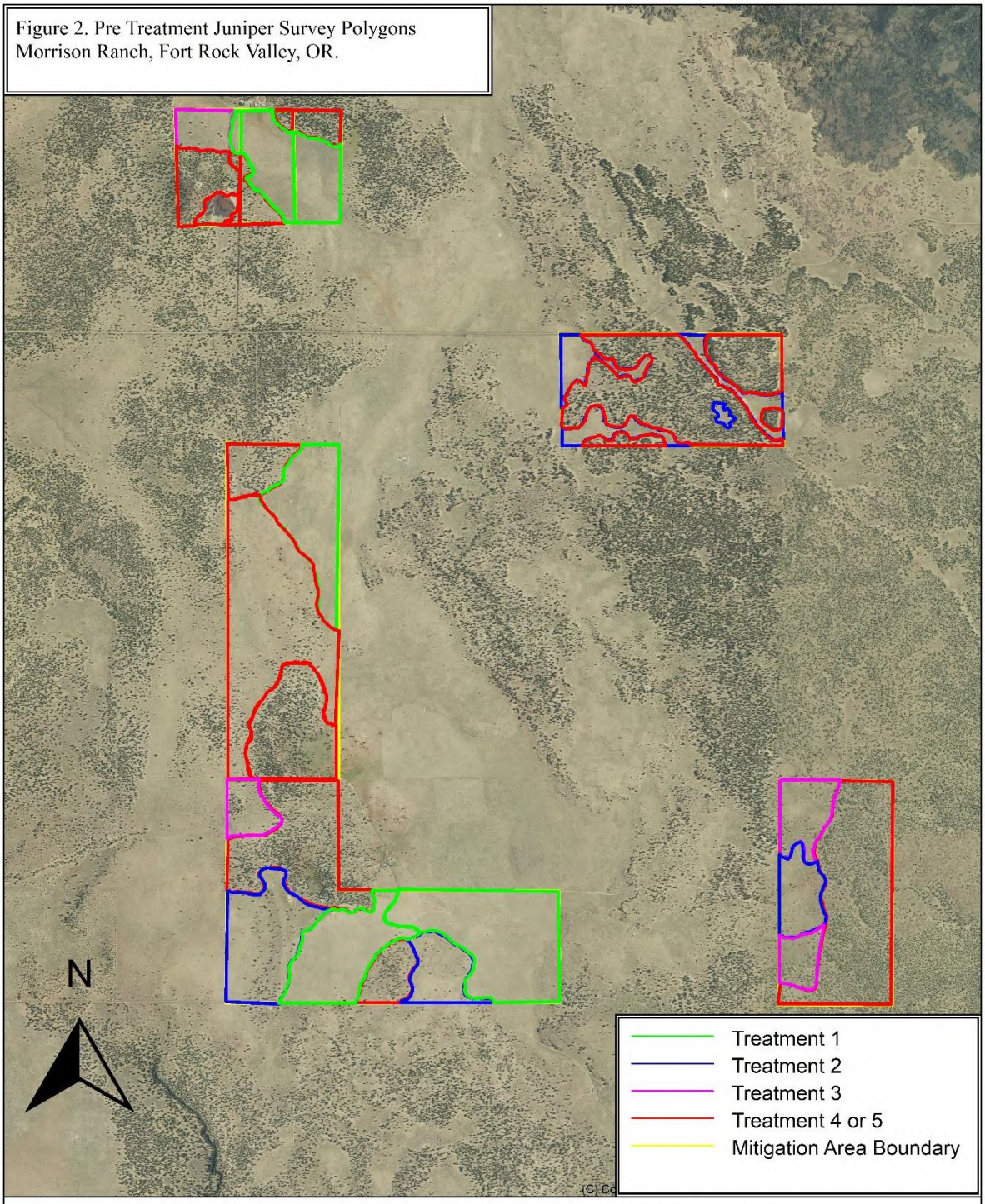
Grass Abbreviations: AGCR-crested wheatgrass, FEID-Idaho fescue

Species in Native Mix: Idaho fescue, blue bunch wheatgrass, Thurber's needlegrass, squirrel tail grass, Sandberg's bluegrass, Indian ricegrass

Table 4. Morrison Ranch, Fort Rock Valley, OR.
Vegetation Association Polygon Comments

Polygon	Comments
35	Cinder Pit
37b	Scattered pre-settlement throughout. Probably was a pre-settlement stand but ~ 100 years ago most trees cut - being replaced with older Post-settlement trees
	Polygon 37a is 22 acres
38	Post settlement trees are 10/ac of trees ~80 years old and <5/ac of trees ~20 years old
39b	Scattered pre-settlement throughout. Polygon 39a is 4 acres
40b	Juniper distribution patchy- large areas of <5 stems/ac. Polygon 40a is 60 acres.
41	Within winter feed lot. Shrubs very sparse.
42	Within winter feed lot. Shrubs very sparse.
43	Denser stand of Pre-settlement and old Post-settlement trees. JUOC <40 years are <5/ac.
	Within winter feed lot. Shrubs very sparse.
44	Sparse stand of pre-settlement. Post-settlement trees ~ 20 yrs old and <5/ac
45	A portion of the area west of the road was an old feed lot. In this area
	post settlement <5/ac. Shrubs CHNA/CHVI.
46	Scattered Pre-settlement throughout.
47	Scattered Pre-settlement throughout.
49	Scattered Pre-settlement throughout.
50	Old rye hay field converted to AGCR ~ 40 years ago
51	Old rye hay field converted to AGCR ~ 40 years ago
52	Ward Well #1 on tablet pictures
53	Shallow draw bottom between degrading lava flows. Ward Well #4 on tablet pictures
54	Shallow draw bottom between degrading lava flows.
55	Better soil inclusion in degraded lava flow
56	Shallow draw between degraded lava flows. Juniper density increases south to north
57	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
58	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
59	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
60	Degraded lava. Inclusions of sandy loam soils which have the most post settlement
62	Scattered Pre-settlement throughout.
63	Scattered Pre-settlement throughout.
64	Scattered Pre-settlement throughout.

Figure 2. Pre Treatment Juniper Survey Polygons
Morrison Ranch, Fort Rock Valley, OR.



1939 acres
Date: 05/14/20
Scale: 1 inch = 2,916 ft.

Location: 10 0678120 E, 4807203 N
Fosters Natural Resource Contracting

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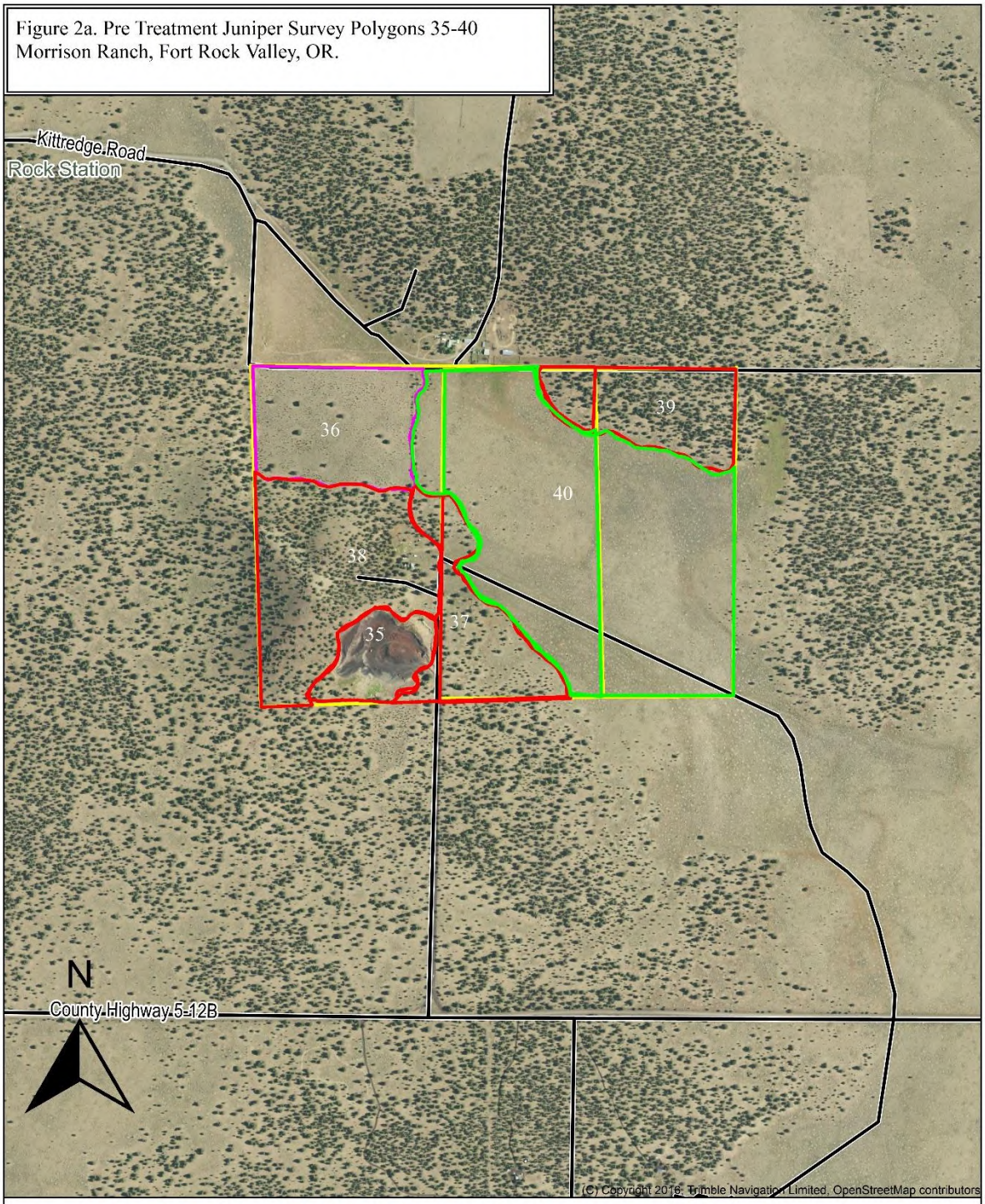
Figure 2a. Pre Treatment Juniper Survey Polygons 35-40
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0676334 E, 4810132 N
Fosters Natural Resource Contracting

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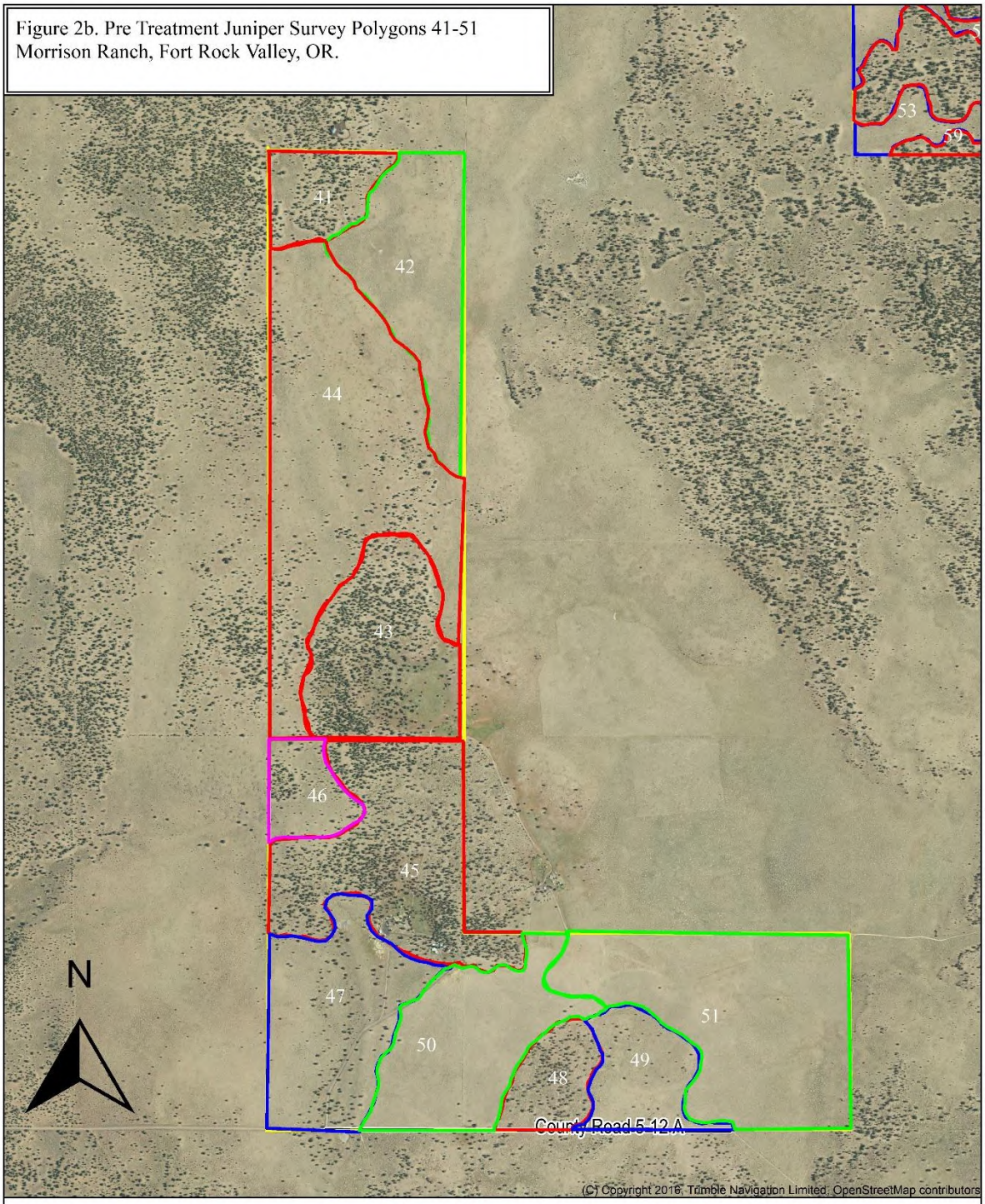
Figure 2b. Pre Treatment Juniper Survey Polygons 41-51
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,666 ft.

Location: 10 0677139 E, 4806452 N
Fosters Natural Resource Contracting

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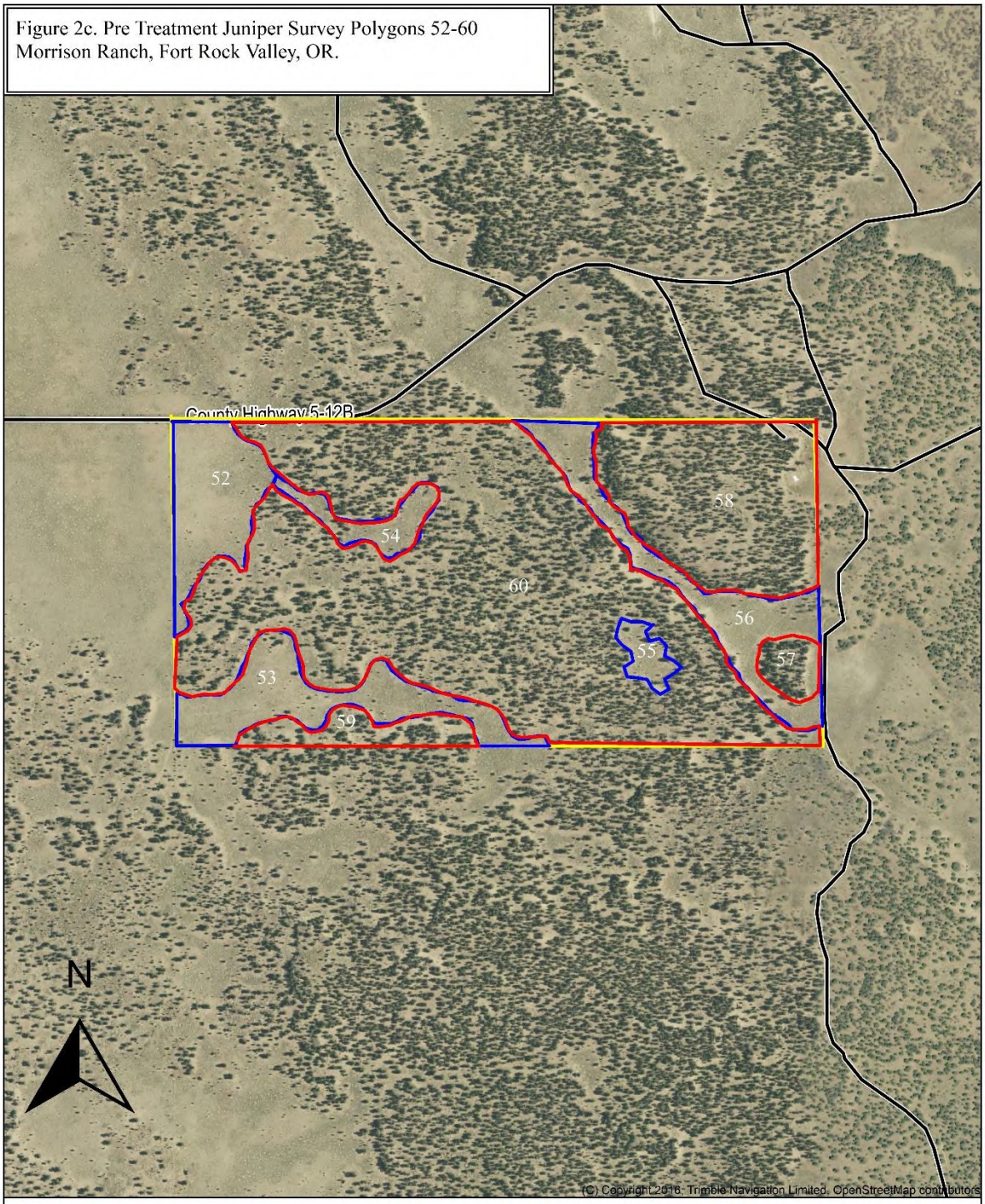
Figure 2c. Pre Treatment Juniper Survey Polygons 52-60
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0679375 E, 4808720 N
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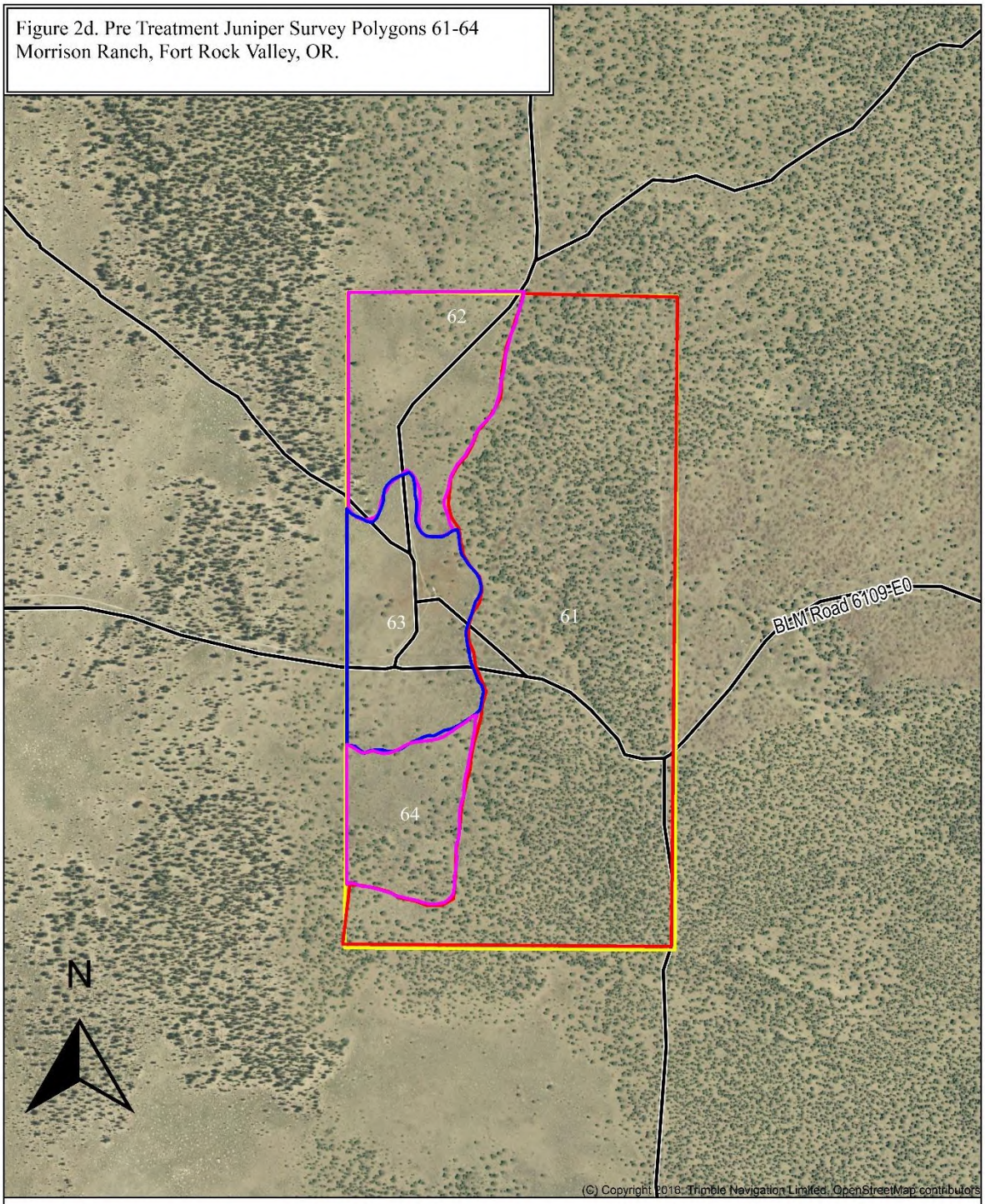
Figure 2d. Pre Treatment Juniper Survey Polygons 61-64
Morrison Ranch, Fort Rock Valley, OR.



Date: 05/14/20
Scale: 1 inch = 1,000 ft.

Location: 10 0680626 E, 4805201 N
Fosters Natural Resource Contracting

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Conclusions

In their existing condition the mitigation properties have a better mosaic of forage and cover areas for big game winter range than what is available on the Facility. Vegetation associations on the Facility are 95% sagebrush shrubland and the remaining 5% does not include forest vegetation associations. The mitigation properties currently have a forage:cover ratio of 62:38 (Nine Peaks 70:30, Morrison 45:55). However, juniper encroachment into the forage areas, if left unchecked will reduce forage quality and quantity. Juniper treatments in the mitigation area are designed to reduce juniper encroachment in sagebrush shrubland vegetation associations, and recruit or protect cover values in the forest vegetation associations which will maintain and improve habitat values for wintering big game.

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Appendix 2

WLIP Site Habitat Assessment Protocol

Prepared For:

Obsidian Solar Center LLC

5 Center Point Drive, Suite 250

Lake Oswego, OR, 97035

Prepared By:

Fosters Natural Resource Contracting

16981 Highway 395, Lakeview, OR, 97630.

541-219-0252

fostersnrc@gmail.com.

Introduction

Obsidian Solar Center LLC (Obsidian) is applying for a Site Certificate from the Oregon Energy Facilities Siting Council to build and operate the Obsidian Solar Facility in the Fort Rock Valley of Lake County, Oregon. A condition of the certificate will require Obsidian to mitigate for the facility's impacts to Category 2 big game winter range habitat and they have submitted a draft Habitat Mitigation Plan (HMP) for review and approval (Attachment 1). The HMP proposes establishment of a Working Lands Improvement Program (WLIP) on two properties totaling 6,534 acres in the Fort Rock Valley (HMP Attachment 3). The HMP identifies 5 steps to establish the WLIP (HMP Section 3.3, page 8). The purpose of this document is to describe the methods to complete a general habitat assessment of big game winter range and a pre-treatment inventory of juniper stands and weeds on the WLIP properties.

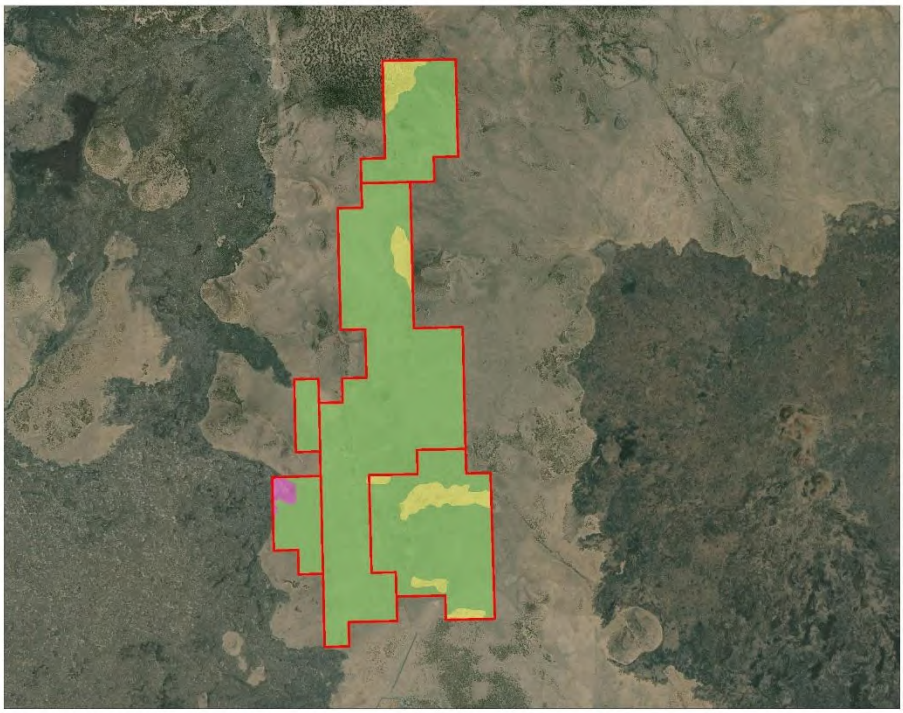
Habitat Assessment Protocol

Figures 1a and 1b from the HMP (Attachment 1) identifies juniper woodland, non-native grassland and sagebrush shrubland as the vegetative types on the WLIP properties. It is very difficult to differentiate grass and shrub species from a desk top classification using photo imagery. The purpose of the habitat assessment is to better define plant associations and delineate their boundaries. The assessment will focus on forage and cover conditions for big game species, specifically mule deer (*Odocoileus hemionus*) and rocky mountain elk (*Cervus elaphus nelsoni*), by walking variable width transects throughout the 6,534 acres within the various plant associations to determine species present and vegetative condition. Transect width needs to be determined by the vegetative condition present at the time of inventory (e.g. delineating the boundary of a noxious weed infestation will require substantially tighter transect lines than determining the size and condition of a crested wheatgrass seeding), which will be conducted in Spring (April – May). The habitat assessment may be conducted in Summer or Fall, if completed by individuals experienced in plant identification when desiccated.

A biological assessment (Obsidian Solar, Biological Assessment, 2018 Unpubl. Report) of the solar development properties determined the primary impact to big game winter habitat was loss of forage. The primary forage species available in the Fort Rock Valley are sage brush, bitterbrush and perennial forbs for deer, and those species plus native and non-native grass for elk. Coe et al. (2017) reported that juniper stands are selected for winter habitat by deer and numerous studies have shown the importance of winter cover for elk. Cover availability will be determined during the juniper inventory.

Assessment of the non-native grassland association will identify: Dominate species and condition of grass, and perennial forbs. Dominate species and condition of shrubs (if any). Level of juniper encroachment. Assessment of the sagebrush shrubland association will identify: Dominate species and condition of shrubs. Level of juniper encroachment. Presence and species

of native grasses and forbs. Boundaries of vegetation associations will be delineated using GPS and mapped.



Stantec

Potential Mitigation Area
Quarry
Habitat Types
Juniper Woodland
Non-Native Grassland
Sagebrush Shrubland

N

0 2,000 4,000 Feet

1 in = 4,000 feet

Project Location
Lake County, Oregon

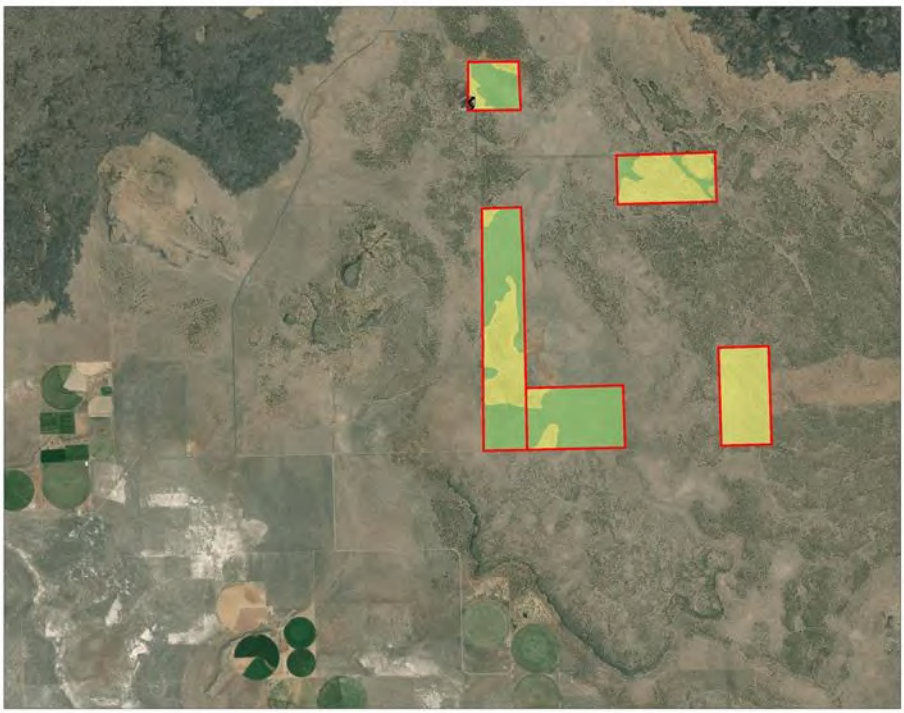
Prepared by BRT on 2020-02-10
TR by DR on 2020-02-11

Client/Project
165704672

Obsidian Solar LLC
Obsidian Solar Center

Title
Figure 1A. Habitat Types in the Mitigation Area on Borror Property

Disclaimer: This document has been prepared based on information provided by others as cited in the Notes section. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.



Stantec

Potential Mitigation Area
Quarry
Habitat Types
Juniper Woodland
Non-Native Grassland
Sagebrush Shrubland

N

0 2,000 4,000 Feet

1 in = 4,000 feet

Project Location
Lake County, Oregon

Prepared by BRT on 2020-02-10
TR by DR on 2020-02-11

Client/Project
165704672

Obsidian Solar LLC
Obsidian Solar Center

Title
Figure 1B. Habitat Types in the Mitigation Area on Morrison Property

Disclaimer: This document has been prepared based on information provided by others as cited in the Notes section. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

Juniper Inventory

Juniper stands will be classified to Phase. Age of juniper within the stands will be defined as either pre or post settlement (Miller et al., 2007). Below is the juniper Phase classification which will be used.

Phase 1 stands are defined as having post-settlement juniper that are either not abundant or old enough to compete with shrubs as indicated by the majority of the shrubs in the stand being robust with few or no dead limbs. Perennial herbaceous vegetation is abundant and bare soil is > 50%

Phase 2 stands have post-settlement juniper that are abundant and old enough to impact shrub growth, and shrub or herbaceous species establishment, which usually results in greater than 50% bare soil. Phase 2 stands are further defined as being early or late: Shrubs in early Phase 2 stands are still relatively abundant but dead limbs within individual plants are common. Skeletons of dead shrubs are common throughout the stand and seedling shrubs are uncommon. Shrubs in late Phase 2 stands are common but there are more dead than live limbs within individual plants. Skeletons of dead shrubs are common throughout the stand and seedling shrubs are absent or restricted to a few individual plants.

Phase 3 stands have pre and/or post-settlement juniper that are abundant and old enough to have out competed most of the shrubs in the understory. Shrubs remaining are stunted with few live limbs and bare soil usually exceeds 70%, unless nonnative annual grasses have encroached into the stand. Skeletons of dead shrubs are generally uncommon because they have already broken down.

Pre-settlement juniper are older than 200 years and established prior to or at the approximate time of European settlement of the western U.S. Within the Fort Rock Valley, they occur as individual trees within a younger stand or as distinct stands of juniper dominated by pre-settlement trees.

Boundaries of juniper stands will be delineated using GPS and mapped. If individual pre-settlement juniper trees are found their location will be recorded so they can be retained in any scheduled treatment.

Noxious Weed Inventory

A noxious weed inventory will be conducted on the WLIP properties. All disturbed sites, roads and areas near water will be surveyed for noxious weeds (Table 1), medusa head rye (*Taeniatherum caput-medusae*) and ventenata (*Ventenata dubia*). The location and boundaries of any infestations found will be recorded using GPS and mapped. Additionally, the location and boundaries of all infestation found during the habitat assessment and juniper inventory will be recorded using GPS and mapped, (Bartz, 2006).

Table 1: Weed Species of Concern

Weed Species Common Name	Scientific Name	Threat Level
Canada Thistle	*Cirsium arvense*	3
Common Reed	*Phragmites australis, ssp. Australis*	0
Cutleaf teasel	*Dipsacus Laciniatus*	1
Dalmatian toadflax	*Linaria dalmatica*	2
Diffuse knapweed	*Centaurea diffusa*	1
Dyer's Woad	*Isatis tinctoria*	3
Eurasian watermilfoil	*Myriophyllum spicatum*	0
Field Bindweed	*Convolvulus arvensis*	1
Hoary Cress (whitetop)	*Lepidium draba,Lepidium et. Al*	2
Kochia	*Kochia scoparia*	3
Leafy Spurge	*Euphorbia esula*	0
Mediterranean sage	*Salvia aethiopis*	3
Medusahead rye	*Taeniatherum caput-medusae*	3
Musk thistle	*Carduus nutans*	2
Myrtle Spurge	*Euphorbia myrsinites*	2
Perennial Pepperweed	*Lipidium latifolium*	1
Puncturevine	*Tribulus terrestris*	2
Purple loosestrife	*Lythrum salicari*	1
Rush Skeletonweed	*Chondrilla juncea*	0
Russian knapweed	*Acroptilon repens*	1
Saltceder	*Tamarix ramosissima*	1
Scotch broom	*Cytisus scoparius*	0
Scotch thistle	*Onopordum acathium*	3
Spotted Knapweed	*Centaurea stoebe (c.maculosa)*	2
Spinny Cockelbur	*Xanthium spinosum*	3
Summer Pheasant eye	*Adonis vernailis*	2
Sulfur cinquefoil	*Potentilla recta*	2
Yellow Starthistle	*Centaurea solstitialis*	1
Yellow Toadflax	*Linaria vulgaris*	3

Threat key

0 Watch For
1 Establishing
2 Controllable
3 Widespread
x Not detected

Literature Cited

Bartz, E., 2006. Noxious weed plan. Las Vegas Field Office, Nevada BLM: A plan for integrated weed management. Appendix 3: Weed Survey Protocol. Unpubl. Report. pp. 16-17.

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Attachment 1

Obsidian Solar Center Habitat Mitigation Plan

(Provided Under Separate Attachment)

Attachment 2

Obsidian Solar Center

2018 Habitat Assessment and Biological Resources Field Report

(Provided Under Separate Attachment)

TARDAEWETHER Kellen * ODOE

From: Albrich, Elaine <ElaineAlbrich@dwt.com>
Sent: Monday, June 8, 2020 8:58 AM
To: TARDAEWETHER Kellen * ODOE
Cc: WOODS Maxwell * ODOE; ESTERSON Sarah * ODOE; Albrich, Elaine; Michelle Slater; David Brown
Subject: Obsidian Solar Center - Response to SHPO Comments
Attachments: Obsidian_response to SHPO supplemental DPO comments_06082020.pdf

Kellen –

Please find attached Obsidian's response to SHPO's DPO comments dated May 15, 2020. Thank you! Elaine

Elaine R. Albrich
Davis Wright Tremaine LLP
1300 SW Fifth Avenue, Suite 2400 | Portland, OR 97201
Direct: (503) 778-5423 | Cell: (503) 250-4429 | elainealbrich@dwt.com
Assistant: Allison Bainter | Direct: (503) 778-5424 | allisonbainter@dwt.com

Anchorage | Bellevue | Los Angeles | New York | Portland | San Francisco | Seattle | Washington, D.C.

June 8, 2020

VIA EMAIL

Kellen Tardaewether
Senior Siting Analyst
Oregon Department of Energy
550 Capitol St. NE
Salem, OR 97301

Re: Obsidian Solar Center LLC – Response to SHPO Comments

Dear Kellen:

On May 15, 2020, the Oregon State Historic Preservation Office ("SHPO") submitted comments to the Oregon Department of Energy ("ODOE") responding to (a) questions posed by ODOE and (b) comments provided by Obsidian Solar Center LLC ("Applicant') on the Draft Proposed Order for the Obsidian Solar Center ("DPO"). This letter provides Applicant's response.

EFSC Historic, Cultural and Archeological Resources Standard

The EFSC standard governing historic, cultural and archeological resources requires that EFSC find that the construction and operation of the facility, taking into account mitigation, are not likely to result in significant adverse impacts to resources set out in OAR 345-022-0090(1). Renewable energy facilities such as the proposed facility are exempt from the historic, cultural and archeological resources standard, although EFSC may use the standard to impose conditions in the site certificate. Applicant has provided evidence and analysis to demonstrate compliance with the historic, cultural and archeological resources standard, taking into account mitigation. In addition to mitigation, Applicant has demonstrated compliance with the EFSC standard using avoidance and minimization measures, as discussed further below.

The SHPO comments raise questions about what amounts to "mitigation." Under the EFSC standard, mitigation may include agreements with tribes and other stakeholders. For example, in the Boardman Solar Energy Facility Final Order, dated February 23, 2018 ("Boardman Order"), EFSC found that an agreement between the applicant and Confederated Tribes of the Umatilla Indian Reservation ("CTUIR") constituted mitigation for potential impacts to an NHRP eligible resource identified by the CTUIR. See Boardman Order, p 149-50. There is precedent for treating agreements with tribes as mitigation to meet the standard. In some instances, the measures amounting to mitigation may not be disclosed in the EFSC record to protect confidential information about significant cultural resources.

The draft Cultural Mitigation and Monitoring Plan, included as Attachment S-3 to the DPO summarizes the avoidance and minimization measures under the EFSC historic, cultural, and archeological resource standard (see Section II). It also provides a list of mitigation measures that Applicant proposes to ensure that the proposed facility complies with the EFSC historic, cultural and archeological resources standard. Together, these measures are robust, and were developed in consultation with the Tribes, ODOE, and SHPO. ODOE may rely on the draft CCMP to support findings of compliance under the EFSC historic, cultural and archeological resources standards. While SHPO's comments appear to take issue with some language used to describe the avoidance, minimization, and mitigation measures, these are irrelevant for purposes of determining compliance with the standard and mostly reflect SHPO's disconnect with the legal and procedural standards in the EFSC process. SHPO's repeated comments about how Section 106 works and what constitutes mitigation under SHPO's regulations are misplaced.

Clarifications for Purposes of the Record

- Applicant engaged The Klamath Tribes and the Burns Paiute Tribes over the course of developing the preliminary application for site certificate, the completed application for site certificate, and the CCMP. The Klamath Tribes provided comments into the record regarding the field surveys and proposed avoidance, minimization, and mitigation measures. See *Letter from The Klamath Tribes Tribal Council to John, Pouley, SHPO,* dated August 8, 2019 (Attachment 1). This letter describes the agreement reached between the Tribes and Applicant along with the Tribes' review and acceptance of the results and recommendations in the project's archeological reports. SPHO misrepresents the Tribes' involvement and input (or asserted lack thereof) multiple times throughout its comments. See also *Letter from The Klamath Tribes Tribal Council to Todd Cornett, ODOE,* dated July 18, 2029 (Attachment 2) included as Attachment S.5.1.3 in Exhibit S.

Specific Response to SHPO Comments

- DPO JP1: see response above under Clarifications for Purposes of the Record.

- DPO JP 2: Applicant proposes the following revisions to the DPO, lines 28-32 on page 6 of SHPO comment PDF:

  The applicant explains in ASC Exhibit S that prehistoric sites were preliminarily evaluated as eligible, 29 potentially eligible, or not eligible for nomination to the NRHP, assessed under NRHP Criterion D. Based on the consultant recommendations in the pedestrian survey report ~~and site visits with Klamath Tribal representatives~~, the applicant identified seven prehistoric sites treated as eligible, 22 prehistoric sites treated as potentially eligible, and 69 prehistoric sites treated as not eligible for listing on the NRHP. These preliminary recommendations were subsequently replaced to treat all of the archaeological sites and isolates as part of an archaeological district.

- DPO JP5: Applicant understands SHPO's role in significance determinations and proposes no revision.

- DPO JP 8: SHPO objects to the use of the term "overestimate" when describing the methodology under the Archeological Testing and Excavation Methods Plan. This

sentence is not necessary for findings of compliance under the EFSC standard so rather than debate with SHPO over the nuance of the word, Applicant proposes to delete the sentence highlighted by JP8.

- DPO JP10: SHPO appears to be reiterating its disagreement with Applicant's original archaeological consultant and asserting its role in determining project effects. This comment is not material to the proposed findings and Applicant proposes no revision.

- DPO JP 11: see response above under Clarifications for Purposes of the Record.

- DPO JP15: see response above under Clarifications for Purposes of the Record.

- CCMP JP1: Applicant proposes to replace "cultural resources" with "resources protected under the EFSC standard for historic, cultural, and archeological resources."

- CMMP JP2: SHPO objects to calling the agreement with the Klamath Tribes "mitigation." SHPO again appears to be reiterating its disagreement with Applicant's original archaeological consultant and asserting its role in determining project effects. Applicant proposes to replace the words "mitigation obligations" with "avoidance, minimization and mitigation measures" in Bullet 4 of Section III to reflect more accurately the nature of the measures Applicant agrees to implement during facility construction.

- CMMP JP3: It is obvious Applicant and SHPO continue to disagree about what is required to demonstrate compliance under the EFSC standard for historic, cultural, and archeological resources and what constitutes "mitigation" under the standard. Applicant proposes to revise the highlighted sentence as follows:

  "The archaeological excavations serve as delineation of subsurface archaeological deposits and mitigation for those expected construction impacts."

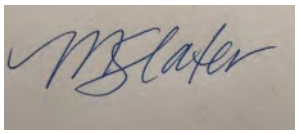
- CCMP JP4: Applicant suggested the language "an appropriate repository" to indicate that somewhere else other than the University of Oregon Museum of Natural and Culture History (UOMNCH) may be the repository if approved. A simple revision to reference UOMNCH "or an approved alternate location" would resolve SHPO's comments.

- CCMP JP5: Applicant proposes revising Bullet 5 as follows:

  Applicant will provide copies of all reports for all work conducted under the permits ~~monitoring and discoveries within the Facility site boundary~~ to ODOE, SHPO, the Klamath Tribes, and the Burns Paiute Tribe. Applicant will also provide copies of all reports for all work conducted under the permits ~~monitoring and discoveries~~ within Section 16 of the Facility site boundary to the Oregon Department of State Lands.

Thank you for your consideration. Please let us know if there are questions or if further discussion is needed.

Very truly yours,



Michelle Slater

cc: David W. Brown
Terry Ozbun
Elaine Albrich

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TARDAEWETHER Kellen * ODOE

From: Albrich, Elaine <ElaineAlbrich@dwt.com>
Sent: Thursday, July 16, 2020 5:59 PM
To: TARDAEWETHER Kellen * ODOE
Cc: ESTERSON Sarah * ODOE; Michelle Slater; David Brown; Albrich, Elaine
Subject: Obsidian/ Response Matrix to DPO Public Comments and Attachments (July 16, 2020)
Attachments: Obsidian_Response to DPO Comments_matrix.docx; Attachment 1_Foster Natural Resource_Rodent Letter.pdf; Attachment 2_ODFW General Season Antlerless Elk Damage Tag.pdf; Attachment 3_ODFW Elk Damage on Private Land Presentation.pdf; OSCAPP WLIP Juniper Treatment Plan_Final_05192020 revised 07142020.docx; Obsidian__Attachment 1_OSC_habitat_mitigation_plan_022120_final_revised_05142020 and 07142020.docx

Hi Kellen –

Please find attached Applicant's response to public comments received on the Obsidian Solar Center DPO. Also attached are the three attachments referenced in the response matrix along with the updated HMP and Juniper Treatment Plan in response to ODFW's June 11 comment email. Please let us know if you have questions. FN 1 in the matrix explains the redlines in the HMP and JTP.

We received the ODFW letter you sent over this afternoon. We are working to review and are hoping to provide a written response by EOD Friday but that may be ambitious.

Thank you – Elaine

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	Commenter	Issues Raised	Obsidian's Response
1.	John Pouley, Assistant State Archaeologist, OPRD	See Applicant's Response to SHPO DPO Comments, dated June 8, 2020.	See Applicant's Response to SHPO Draft Proposed Order ("DPO") Comments, dated June 8, 2020.
2.	Mark and Dorothy Ferns, area residents	Concern about main route, roads are like powder. Live close to the road and livestock graze next to road. Go through the Fines property as alternative. Support the project but don't like applicant using dirt road and having to deal with dust, cattle feed covered in dust.	Applicant proposes several measures to minimize dust during construction, including road construction activities and road use. Roads will be watered during construction as much as is necessary to adequately control dust. In addition, clean crushed gravel (with no fines) may be added to the primary access road to help minimize dust as needed. Swinerton Builders will also be providing oral testimony at the July 20th DPO hearing regarding its experience with dust control in this and similar landscapes, dust and erosion control measures, and best practices. Applicant proposes a condition of approval requiring Applicant to post a sign along the main entrance to the Facility with a phone number neighbors can call to report dust concerns (a "Dust Control" reporting line).
3.	Seth Thompson, Aviation Planner, Oregon Department of Aviation	Project may require airspace review by FAA and ODA subject to CRF Title 14, Part 77 and must comply with FAA Part 77.9 Construction or Alteration Requiring Notice, and Part 77.17 Obstruction Standards if >	No response is needed.

		200 feet and located within certain distances to airports. Confirmed no airports in the vicinity and project complies with FAA Part 77.9 standards. Included reference to FAA 2018 Technical Guidance for Evaluating Selected Solar Technologies on Airports for ODOE reference.	
4.	Gail Carbiener (unknown)	Provided GLO Map (1913) showing Fort Rock to Christmas Valley Road running through the site. May be able to work with "us" [not identified] on adding historic signage in the area.	Evidence of a historic trail/road was not identified during the field work described in Exhibit S.
5.	Sarah Reif, Energy Coordinator, ODFW (4-24-20)	See Applicant's Response to ODFW DPO Comments, dated May 18, 2020.	See Applicant's Response to ODFW DPO Comments, dated May 18, 2020.
6.	Elaine Albrich/Obsidian	N/A	N/A
7.	Brad Thorsted, area resident	Resident works for Lake County Road Department and is concerned about solar projects in north Lake County because of the cost and time, material, and labor to repair roads. People drive too fast and there are wrecks. Workers have no respect for where they are working. Understand that these companies can walk away and not have to deal with removal or cleanup. Do not support solar projects.	Applicant proposes best management practices to address dust control during construction in Exhibit I and the DPO provides proposed findings and conditions to minimize dust under the EFSC Soil Protection Standard. See Applicant's response to DPO Comment 2 above which also raised concerns about dust. Swinerton Builders will also be providing oral testimony at the July 20th DPO hearing regarding its experience with dust control in this

			and similar landscapes, dust and erosion control measures, and best practices. The DPO addresses the concern about road maintenance and repair. *Recommended Public Service Condition 1* requires that prior to construction, Applicant enter into a road use agreement with the County. In addition, Applicant will be required to comply with a Construction Traffic Management Plan. Under the road use agreement, Applicant will bear the costs of repairing the road if any damage occurs during construction. Applicant has had multiple conversations with the Lake County Road Superintendent and anticipates no difficulty in reaching a satisfactory road use agreement with maintenance requirements. In addition, Swinerton Builders will provide oral testimony at the July 20th DPO hearing regarding road use and maintenance, its practices, and its experience with road use and maintenance agreements (including in Lake County).
8.	Bradley Winters, James Williams Mark Albertson, Lake County Commissioners, Special Advisory Group	Clarifying that Mr. Thorsted commented in his personal capacity and his opinion does not represent those of Lake County. Lake County is in favor of the proposed project; the county has experience with solar construction and impacts to roads. Obsidian	Applicant thanks the Lake County Commissioners for their letter and support of the project.

		has built responsibility in Lake County for several years. Lake County has the tools to supervise roads and commitment from Obsidian to be responsible for damage.	
9. 9.1	Sarah Reif, Energy Coordinator, ODFW (5-18-20) Sarah Reif, Energy Coordinator, ODFW (6-11-20)	See Applicant's Response to ODFW DPO Comments, dated May 18, 2020. <u>WLIP Pre-Treatment Juniper Survey</u>: ODFW agrees the results look appropriate. <u>WLIP Juniper Treatment Plan</u>: ODFW supports the treatment design, layout, methodology, and weed management described in the plan. For monitoring, ODFW asks for additional clarification. In ODFW's view, there are two tracks for monitoring: (1) to ensure that treatments successfully reduce juniper density and limit encroachment by young juniper; and (2) to ensure that treatments do not result in noxious weed establishments. On point one, ODFW finds that the proposed monitoring approach for success of juniper treatment is clear and appropriate. On point two, ODFW recommends incorporating the monitoring methodology	See Applicant's Response to ODFW DPO Comments, dated May 18, 2020. In response to ODFW's June 11, 2020 comments, Applicant has revised the Juniper Treatment Plan and the HMP to address ODFW's comments and provides the updated plans in this submittal.[1] In addition to ODFW's suggested revisions, Applicant proposes two refinements for the Reveg/Weed Control Plan related to the success of treatment: • Note in Section 2.2.1 that the seed mix may be modified in consultation with ODFW and LCCWA if nonnative seeds (like Crested Wheatgrass and/or Covar sheep fescue) may be needed to more aggressive respond to noxious weeds. • Revise Section 2.2.2 to change the seeding timing to November to early March in order

[1] In the HMP, new July redline revisions are noted with comment bubbles (preexisting redline from May is also included). For the Juniper Treatment Plan, the redline denotes the July redline revisions (no prior redline).

		from the Revegetation and Noxious Weed Control Plan ("Reveg/Weed Plan"). For juniper treatment success criteria, ODFW recommends revising the "maintenance" section in the plan to "success criteria" and use that section to address the success criteria. ODFW supports the success criteria identified. ODFW recommends incorporating the Reveg/Weed Plan success criteria and monitoring requirements into the juniper treatment plan and HMP. In addition, ODFW would like to see what remedial actions would take place if thresholds are exceeded.	to take advantage of soil moisture needed for germination by April. Finally, Applicant revised Section 4 of the Juniper Treatment Plan to provide that monitoring reports will include a description of necessary remedial actions in the event any ae necessary. The specific detail of any particular remedial action (e.g., re-seeding, additional noxious weed treatment, additional juniper treatment) will depend on the condition that requires additional mitigation. The monitoring reports will document remedial actions take to date, additional remedial actions planned for areas that are not apparently trending toward success, and the anticipated dates of completion of each of these actions. Remedial actions will be implemented as needed. With these revisions, Applicant maintains that it has fully responded to ODFW's comments raised to date.
10.	Justin Ferrell, Manager, Fort Rock/Silver Lake SWCD	Key Issues of Concern 1. High risk of wind erosion on disturbed soil which have a "Wind Erodibility Group 1" during and after Facility installation. 2. Adequate mitigation measures to prevent excessive wind erosion during construction	The report provided with the comment letter was developed by the SWCD Board with assistance from a retired soil scientist. The letter identifies 6 key issues. Applicant appreciates SWCD's comments and also acknowledges the importance of managing for soil erosion and weed control. Applicant, however, notes that LeeRoy Horton, an active

		phase of Facility and feasibility of establishing adequate vegetative cover to project soil form wind erosion long term. 3. Grading and leveling of soil in areas of slopes ranging from 2 to 20 percent and the potential to expose and/or mix near neutral pH surface soils and subsurface soil horizons having a moderately to strongly alkaline reaction. Thus further inhibiting the establishment of vegetative cover. 4. Soil compaction occurring as result of construction activities resulting in loss of soil macro porosity and increased soil stretch that could lead to increased water runoff, surface erosion, as well as soil conditions favorable to weeds. 5. Identification and control of non-native invasive weeds and noxious weeds. 6. Monitoring of the above issues and implementation of adaptive management when needed.	opponent of the Obsidian project and a petitioner in the prior LUBA appeal, is the Chair of the SWCD Board. 1. Wind Erosion. Applicant proposes several measures to minimize dust from wind erosion which the Board does not appear to consider. First off, Applicant proposes to brush beat and mow vegetation to minimize grading and blading (a measure recommended by the SWCD Board). If native roots do not adequately provide erosion control, crimped straw or straw mulch or another BMP will be used. Swinerton's philosophy is that the erosion control plan and dust control plan are living documents. Further, Swinerton has worked with the leading racking manufacturer in the U.S. to develop a proprietary design that allows us to follow the native terrain and greatly reduces the grading necessary. Additionally, Swinerton developed an above ground DC collection system that will eliminate miles of DC trenches. Swinerton also minimizes roads to only what is needed for fire safety (i.e. access to inverters) and does not build temporary construction roads. Areas temporarily disturbed during construction will be revegetated as soon as construction in the area is completed (rather than waiting until all construction is complete). For areas that

			cannot be reseeded immediately, the areas would be stabilized using straw mulch, hydro mulch, erosion control fabric, or other BMPs as practical. SWCD Board implies that large volumes of soil will be moved during construction, which is not the case. Swinerton will address this issue further during its DPO hearing testimony. 2. Adequate Mitigation for Wind Erosion. See above. In addition, Applicant's Revegetation and Noxious Weed Control Plan ("Reveg/Weed Plan") contains a seed mixture developed in consultation with ODFW and the Lake County Cooperative Weed Management Area (LCCWMA) and may be adapted or modified as needed, in consultation with ODFW and LCCWMA (e.g., if ODFW or LCCWMA thinks SWCD Board's suggestions are advisable, then Applicant will work with ODFW/LCCWMA to modify the seed mixture). The Reveg/Weed Plan also provides for seed planting methods and schedule to ensure that reseeding is conducted during times of the year when success is most likely. Applicant strongly disagrees with the SWCD Board's recommendation to spray the entire site boundary and establish a monocrop before construction.

			3. Mixing of Soils/Soil pH. Grading and blading will be minimized to the extent possible to avoid ground disturbance and preserve roots of existing vegetation. As mentioned above, Swinerton has worked with the leading racking manufacturer in the U.S. to develop a proprietary design that allows us to follow the native terrain and greatly reduces the grading necessary. Additionally, Swinerton developed an above ground DC collection system that will eliminate miles of DC trenches. Swinerton also minimizes roads to only what is needed for fire safety (i.e. access to inverters) and does not build temporary construction roads. Finally, the SWCD Board raises specific concerns with grading in the areas having soil map unit 472 soils. Given the proposed construction methods and BMPs, Applicant maintains that concerns over pH are overstated. Further, some of these areas will be located in avoidance areas and left undisturbed. 4. Soil Compaction. The SWCD Board has concerns about soil compaction from equipment used during construction and then suggests that Applicant "till or rip disturbed areas in conjunction with revegetation efforts." In other areas of the comment letter, the SWCD Board raises concerns over ground disturbance and recommends minimizing it to the extent

			possible. Applicant maintains that its proposed measures are adequate to ensure that soil compaction is minimized. Contractors will use rubber-tire/rubber-tracked equipment to the extent possible when driving across the project site and will use low ground-pressure equipment and temporary construction mats to minimize soil compaction. The minimization of grading and blading will also help with soil compaction. 5. Noxious Weeds. Applicant appreciates the SWCD Board's support for the Reveg/Weed Plan treatment measures. 6. Monitoring. Applicant will conduct monitoring per the Reveg/Weed Plan, which was developed in consultation with ODFW and LCCWA. The results will be reported in the Facility's annual report to ODOE. If the SWCD Board is interested in the results, it may obtain the annual report from ODOE.
11.	Doris Kittredge, area resident	Oppose solar projects as panels are eyesore. Concerns about impacts to infrastructure and the community in general, and the visual unpleasantness.	Applicant responds to each issue raised: 1. Ms. Kittredge's property is located to the north of the Facility site boundary, near the two "towers" in Area A. Rodent disbursement at most may be 160 feet to maybe .5 miles in the most extreme conditions (e.g., high population year). See Attachment 1 from Foster Natural

		1. Displacement of rodents after brush removal and construction of solar panels with potential damage to crops. 2. Displacement of big game populations in the area, eating crops and damaging fences. 3. Damage to area infrastructure. Pressure on local resources. 4. Solar projects tear up county roads and access roads. The contractors rely on Lake county road department to maintain and repair them. The road department is in lack of funds and operators. 5. As far as payment in lieu of taxes for these projects; the solar companies boast how much they will benefit school, the school is in fine financial shape, and from what we understand if local schools receive these funds, the funds that are supported but the State of Oregon are returned to Salem, thus the funds should be used in other ways, we need these payments in lieu of taxes for deteriorating roads and financially suffering Lake County road department. Perhaps these payments in lieu of taxes can pay off the school bond for construction that recently passed.	Resource Contracting addressing rodent disbursement ("Foster Letter"). As supported by the Foster Letter, ODOE may conclude that any potential displacement of rodents would temporary and would not rise to the level of a significant agricultural impact. 2. The Facility site is located in an area that has large swaths of public land and 1000s of acres within ODFW-mapped Big Game Winter Range. Big game may use different areas of the range depending on a variety of factors, changing throughout the year and throughout the seasons. The areas to the east and the north will remain open rangeland and consist of similar habitat to the Facility site boundary. In addition, Applicant will be protecting and enhancing several thousand acres of rangeland habitat to the north of the Facility site, which will provide better habitat functions as the Facility site. There is continuity of habitat to the east of the Facility site boundary. The potential impacts from fencing big game out of the Facility site boundary may result in some changed movement patterns but are unlikely to result in agricultural impacts (e.g., damage to fencing and eating crops) that rise to the level of significant. ODFW has specific programs to address elk damage on private land. In 2020, ODFW adopted administrative rules for a new

		6. Light pollution - substations/battery packs on look like cruise ships sailing in the night. Concern about lights, one idea to plant trees around these and also improve the landscape that they've torn out. 7. Solar projects are a detriment to the community. They may support a couple of businesses, but not farmers or ranchers or the community in general. The community is supported mainly by the agricultural industry. Once these solar projects are completed, there is no more support, their presence is temporary. 8. Dust problems, road damage. 9. Should require buffers around projects with trees, plants, vegetation. 10. Adverse heat conditions from many, many panels in the community.	elk damage hunt program which allows a new general season antlerless elk damage tag to be used in parts of the state with high elk damage. See Attachment 2; Attachment 3. Fort Rock is not included in one of these newly mapped areas, indicating that elk damage may not be high. Further, landowners may be eligible for the Oregon Landowner Damage Program, which is intended to address damage caused by elk on privately owned lands. See ORS 498.012; ORS 496.158; OAR 635-075-0011. 3. Exhibit U addresses potential impacts to public services and concluded that the Facility would not result in significant adverse impacts to public services, as further evidence in the DPO findings under the EFSC Public Services Standard. 4. The DPO addresses the concern about road maintenance and repair. *Recommended Public Service Condition 1* requires that prior to construction, Applicant enter into a road use agreement with the County. In addition, Applicant will be required to comply with a Construction Traffic Management Plan. Under the road use agreement, Applicant will bear the costs of repairing the road if any damage occurs during construction.

			5. The DPO includes *Recommended Land Use Condition 7* that requires Applicant to enter into a SIP agreement with Lake County prior to operation demonstrating an annual community service fee of $2,000 MWac based on nameplate installed capacity. It also requires Applicant to make a one-time contribution to the North lake County School District Foundation based on $10,000 per MWac capacity. The County decides the use of the community service fee, not EFSC. 6. DPO addresses the concern about outdoor lighting and provides *Recommended Scenic Resource Condition 1* requires that Facility lighting must be shielded and directed downward and lighting must be the minimum amount necessary for safety and security during construction and operation. 7. Applicant provided evidence to address potential impacts to public/community services and surrounding agricultural operations. The DPO contains findings addressing both concerns. Under the Public Services Standard, the DPO finds that the Facility will not result in significant adverse impacts to public/community services and imposes two conditions of approval to ensure that impacts are minimized. Under the Land Use Standard, the DPO finds that the Facility will result in local economic benefits and

			proposes *Recommended Land Use Condition 7* to ensure such benefits. The local community will benefit from property taxes paid each year for the life of the Facility. 8. See Applicant's response under Issue 4 above for addressing road damage; see Applicant's response to DPO Comment 2 (the Ferns) and DPO Comment 10 (Fort Rock/Silver Lake SWCD) above for addressing dust. 9. This comment is not tied to an EFSC standard or particular impact, making it difficult for Applicant to respond. The DPO addresses potential impacts to scenic and recreational resources and finds that the Facility will not result in significant adverse visual impacts to either of these resources. Applicant will take steps to minimize visual impacts and vegetation removal during construction. The DPO provides *Recommended Scenic Condition 1* requiring Applicant to paint battery storage and other buildings earth-tone colors to match or complement the predominate colors of surrounding vegetation and *Recommended General Standard 6* requiring Applicant to restore vegetation to the extent practicable following construction. 10. This comment does not appear tied to an EFSC standard or particular resource, making it

			difficult for Applicant to respond. There is no evidence suggesting that solar photovoltaic technology will result in adverse climate conditions. ODOE's recent solar RAC reached the same conclusion.
12.	Paul Koreiva, area resident	Thank you for the opportunity to comment. Please approve the project. It is the highest and best use for this 3,921 acres located in North Lake County.	Applicant appreciates the letter supporting the project.
13.	Sam Dinsdale, Dinsdale Farm & Equipment LLC, area resident	In favor of the project and believe impact will be a positive one. The clean power will not interfere with farming, sage rats and rabbits. We try to mow sagebrush when it gets in the way of grazing, competition on the edges of alfalfa fields is a familiar battle. It is normal in the winter to see antelope, deer, and elk grazing in the high desert. Farmers use best practices in terms of ground cover to limit dust blowing.	Applicant appreciates the support letter.
14.	Scott and Jana Kittredge, area residents	Concern DSL grazing lease for property located at the intersection of Connely Road and Fort Rock Road and neighboring properties. DSL lease grants Kittredge the right to farm 71.6 irrigated acres and the right to graze an additional 553 acres, excluding the 15 acre quarry site on the	The Kittredges are concerned about a Department of State Lands lease on property that is not included in the Facility site boundary. Area C was previously included in the Facility site boundary but was subsequently dropped

		south side of the property. These activities contribute to the commercial agricultural economy of Lake County and object to conversion of irrigated acres to non-irrigated use. Have additional concerns: 1. Displacement of rodents after brush removal and construction of solar panels with potential damage to crops. 2. Displacement of big game populations in the area, devastating crops and damaging fences. 3. Damage to area infrastructure by construction personnel. Pressure on local resources. 4. Solar projects tear up county roads and access roads. The contractors rely on Lake county road department to maintain and repair them. The road department is in lack of funds and operators. 5. As far as payment in lieu of taxes for these projects; the solar companies boast how much they will benefit school, the school is in fine financial shape, and from what we understand if local schools receive	before Applicant filed the preliminary Application for Site Certificate. Applicant refers ODOE to its responses under DPO Comment 11 (Doris Kittredge) that raised the same issues commenter raises in Items 1-10.

		these funds, the funds that are supported but the State of Oregon are returned to Salem, thus the funds should be used in other ways, we need these payments in lieu of taxes for deteriorating roads and financially suffering Lake County road department. Perhaps these payments in lieu of taxes can pay off the school bond for construction that recently passed. 6. Light pollution - substations/battery packs on look like cruise ships sailing in the night. Concern about lights, one idea to plant trees around these and also improve the landscape that they've torn out. 7. Solar projects are a detriment to the community. They may support a couple of businesses, but not farmers or ranchers or the community in general. The community is supported mainly by the agricultural industry. Once these solar projects are completed, there is no more support, their presence is temporary. 8. Dust problems, road damage. 9. Should require buffers around projects with trees, plants, vegetation.	

		10. Adverse heat conditions from many, many panels in the community.	
15.	Ryan Nielsen, Strategic Researcher Oregon & Southern Idaho District, Council of Laborers	LiUNA supports renewable energy projects and believe that local Oregonians should be employed on these projects. Believe that land use is deeply connected to the labor practices that follow building renewable projects – renewable projects must have strong wages, benefits, and work place protections and only then can we justify transitioning land from agriculture to energy production. Long history of bringing out of state workers and employing non-union workers on renewable projects. Using union labor ensures the building trades can sustain apprenticeship programs in Oregon. Request that state and local governments attach standards to the development of renewable projects to ensure that such projects have apprenticeship requirements, responsible contracting standards, and minority participation requirements.	Applicant appreciates LiUNA District Council of Laborers' comment letter and Applicant's parent company has always worked hard to hire as many people out of the local labor pool as it can find to qualify for the jobs on a project. Most of the jobs associated with the Facility are properly classified as electrical, which limits the types of laborers Applicant or its contractors may hire. However, Applicant is required to ensure that any selected contractor or subcontractor is a qualified contractor. DPO *Recommended Organizational Expertise Condition 2* requires that Applicant select contractors that "have substantial experience in the design, engineering, and construction of similar facilities" to ensure that the EFSC Organizational Standard is satisfied. *DPO Recommended Organizational Expertise Condition 3* requires that Applicant contractually require that all contractors and subcontractors comply with all applicable laws and regulations. Finally, Obsidian and Swinerton have developed successful projects in the County using both union and non-union workers and is proud of the work from both groups.

16. 16.1 16.2 16.3	Mike Reeder (5-15-20) Mike Reeder (6-3-20) Mike Reeder (7-1-20) Mike Reeder (7-13-20)		Mr. Reeder has submitted several letters; all involve similar issues concerning the DPO hearing. Mr. Reeder has not filed substantive DPO comments on behalf of his clients and instead, makes repeated attempts to delay the DPO hearing. Applicant supports ODOE and ODOJ's approach for the July 20, 2020 hearing and maintains that is complies with all applicable state laws and Governor directives. In his May 15, 2020 letter, Mr. Reeder attacked the March 12 DPO notice arguing it was deficient. ORS 469.370 (governing the DPO hearing and notice) is implemented in rule by OAR 345-015-0220. OAR 345-015-0220(3) implements the notice content requirements from ORS 469.370(2). The March DPO notice complied with the notice requirements in OAR 345-015-0220(3). The rule does not expressly track the language in ORS 469.370(2)(d) (requiring that the notice "state that copies of the application and draft proposed order are available for inspection at no cost and will be provided at a reasonable cost" but the rule does provide that the notice must identify the "addresses of the location where the public may inspect copies of the complete application and the website where the application and the draft proposed order may be found." See OAR 345-015-0220(3)(d)-(e).

			The language from the OAR and ORS may not be exact, but the meaning and the purpose is the same – to inform the public how they may access the application materials and a copy of the draft proposed order. The fact that the materials are available on ODOE's website makes them readily available to any one and available electronically at no cost. On page 3 of the March DPO notice, the notice states "[h]ard copies of the proposed Obsidian Solar Center ASC and DPO on the ASC are available for public inspection upon request[.]" The notice also provides links to ODOE's websites where the application materials, the DPO, and other materials related to the facility are posted and readily available for review. Mr. Reeder requested a hard copy of the Application for Site Certificate and the Draft Proposed Order on July 1, 2020. ODOE immediately provided Mr. Reeder with an estimate of the fee to provide him with the requested materials, and to date, Mr. Reeder has not responded. None of Mr. Reeder's clients have requested to review the application materials or the DPO in person or be provided with a hard copy. At this point, the arguments about the availability and access to application materials seems disingenuous. Mr. Reeder and his clients,

			whether directly or indirectly, have provided written comments into the DPO record and make telephone inquiries of ODOE staff regarding the EFSC process. Mr. Reeder, his clients, or any member of the public could have made a request of ODOE staff to set an appointment to view the application materials using social distancing. Having to make an appointment is not a burdensome requirement or hinder access; an appointment to review the materials would be required under any circumstance. The fact that ODOE staff are working remotely does not preclude staff from accommodating a request from the public, if such a request has been made. Mr. Reeder's arguments about "reasonable cost" are speculative at best. The fact that information is publicly available online implies it is available at a reasonable cost. Antiquated arguments about access to the internet is not a defense. There is no obligation to ensure that an individual accesses information, only that access be reasonably available. The March 12 notice complied with the requirements in the rule and the statute. Even if the March 12 notice was deficient because it did not exactly track the language in ORS 469.370(2)(d) that deficiency likely would not render EFSC's subsequent decision invalid.

			Oregon courts have strictly construed notice provisions in the past, holding that when a statute says a notice "shall" include something, the notice must include that thing. See *Dika v. Department of Ins. and Finance*, 312 Or 106, 109, 817 P2d 287 (1991). However, courts have not applied that standard uniformly. In *Clark v. Schumacher*, the Court of Appeals held that a deficiency in a notice issued by the Dept. of Corrections did not invalidate the subsequent rulemaking because the plaintiffs could not show that they were prejudiced by the deficiency. 103 Or App 1, 4–5, 795 P2d 1093 (1990). In a subsequent case, the Court of Appeals distinguished *Dika* from *Clark* by holding that *Dika* only applies in cases where a fiscal impact statement was required to be included and was omitted. *See Oregon Funeral Directors Ass'n v. Oregon State Mortuary and Cemetery Bd*., 132 Or App 318, 322, 888 P2d 104 (1995). Other cases have also turned on this issue: whether a fiscal impact statement or equivalent document was included as part of the notice. *See, e.g., Building Dept., LLC v. Department of Consumer and Business Services*, 180 Or App 486, 43 P3d 1167 (2002); *Oregon Cable Telecommunications Ass'n v. Dept. of Revenue*, 237 Or App 628, 240 P3d 1122 (2010).

			Thus, Oregon courts appear to require strict compliance when a fiscal impact statement or similar document is at issue but apply a prejudice standard for other procedural compliance questions. ODOE subsequently reissued notice on June 17, 2020 and provide more specific information about the availability of the application materials. Therefore, to the extent there was any procedural error, it has been remedied. With respect to Mr. Reeder's arguments regarding Executive Order ("EO") 20-16, Applicant disagrees with his reading of the EO and the related guidance. EO 20-16 is intended to ensure that state agencies are functioning and continuing to operate during the COVID-19 pandemic. It addresses how public agencies may engage in public meetings and hearings notwithstanding statutory or regulatory requirements that may require in person participation. EFSC has delegated authority and appointed the hearings officer to conduct the hearing. The hearings officer is acting on behalf of EFSC to facilitate the opening of the hearing, provide the raise it or waive it statement, and ensure that oral testimony gets placed on the record. The hearings officer serves no discretionary function during the DPO hearing. Whether it is

			EFSC or the hearings officer conducting the DPO hearing has no ramification on the receipt of testimony from Mr. Reeder's clients. In fact, the EO makes clear that any requirement to take testimony in person does not apply and testimony should be submitted in writing. The DPO comment period has been open for written comment since March 12, 2020, meaning Mr. Reeder's clients have had almost four months to access the DPO, review application materials, and provide written comments on the record. The July 20, 2020 DPO hearing was noticed as a special meeting of EFSC and members of EFSC will be attending the hearing in person along with ODOE staff to ensure that the public hearing is conducted "in proximity" to the project and held in a manner that complies with the social distancing requirements for public meetings. The DPO hearing is an official act of the agency and is not an indoor social gathering, as referenced in the Governor's recent advisories. No EO has superseded EO 20-16 that would instruct ODOE or EFSC to conduct the DPO hearing in any other manner than what is planned. The DPO hearing is now scheduled for July 20, 2020 and has been noticed as a special meeting of EFSC, further ensuring that there are no procedural irregularities with the DPO hearing.

			Lake County is in Phase 2 of reopening, which allows up to 50 people indoors subject to social distancing requirements. The venue for the DPO hearing is approximately 2,100 square feet, which can accommodate approximately 58 people with 6-foot distancing in an assembly type of occupancy. If Mr. Reeder's clients are not comfortable appearing in person, they may provide written comments to ODOE, which have the same weight and effect as oral comments on the record. Energy projects are essential critical infrastructure and the businesses and government agencies need to maintain services and functions to continue to work. See CISA Guidance on Essential Critical Infrastructure Workers.
17.	Rose Gibson (unknown)	1. Sure and certain endangerment of wildlife appears to be knowingly and willfully overlooked and disregarded. Concern over the removal of, access to, and use of feeding, bedding, birthing area for big game and birds. 2. Sure and certain endangerment of world ecology by the process of aiming solar panels at the sun, which reflects sunlight	1. Applicant addressed potential impacts to wildlife in Exhibit P and under the EFSC Fish and Wildlife Habitat Standard. The DPO contains conditions that require Applicant to avoid, minimize, and mitigate for potential impacts under the EFSC Fish and Wildlife Habitat Standard. Wildlife is not knowingly and willfully being overlooked or disregarded. 2. Renewable energy, like the proposed Facility, helps reduce the impacts from

		back toward the sun from earth ozone layer and increasing global warming. 3. Sure and certain endangerment of removal of wildlife viewing area available to certain local, respected residents who privacy is proposed to be disregarded by the construction of the project. Recommend project be permanently rejected for just cause.	climate change. The Facility will operate about 30 percent of the time on a full-time equivalency basis, producing about 900,000 MW hours of clean, renewable energy per year, which would reduce the carbon dioxide emissions equivalent to burning almost 3,500 railcars filled with coal each year. See DPO Attachment P-1, Habitat Mitigation Plan, Section I. There is no evidence suggesting that solar photovoltaic technology will result in adverse climate conditions or increase global warming. ODOE's recent solar RAC reached the same conclusion. 3. This comment is not tied to an EFSC standard or a particular resource protected by an EFSC standard, making it difficult for Applicant to respond. It appears that commenter is alleging that private property rights may be impacted by the proposed Facility but Applicant is unable to identify the referenced "wildlife viewing area."
18.	Gray Eagle (unknown)	Concerning sure and certain endangerment of wildlife by knowingly and willfully destroying wildlife habitat on non-arable lands by proposed project which purposes to remove access to and use of feeding, bedding, birthing areas for big game	Applicant refers ODOE to its responses under DPO Comment 17 (Rose Gibson) that raised the same issues as DPO Comment 18 (Gray Eagle). Applicant does not propose to use electric fences and has not used them in the past.

		animals, small game animals, non-game animals and birds by permanent destruction of flora and fauna and replacement of the same by scarification of the land itself, and placement of electrified fencing, roads, buildings, inverters, transformers, transmission lines, power poles, thousands of solar panels, etc. on the proposed project site. Concerning sure and certain endangerment of world ecology by and through the process of aiming solar panels at the sun, which reflects sunlight back toward the sun from the earth through ozone layer, disintegrating ozone and increasing global warming on a grand scale. Every action has an equal and opposite reaction. Continued disregard for the laws of physics will produce undesirable results. Consider for examples; the destruction of fish and wildlife by and through the construction and use of dams on nation's rivers. The end results do not justify the means. Concerning the sure and certain endangerment of, and removal of wildlife by permanent processes by and through the proposed project, the area of land now viewable by certain local respected residents and the residents themselves are	

		now held in a state of complete and total disrespect by the person or persons responsible for proposing the project. The immense size of that proposed solar project should in no wise be permitted to over-rule or over-ride the rights of adjacent property owners. Recommend project be permanently rejected for just cause.	
19.	Paul Hawkins, Milwaukie, Oregon	Commenter has seen solar fields in Nevada and Owyhee County, Idaho and that seems like an ideal place for solar technology.	No response provided.
20.	Bill Richardson, Rocky Mountain Elk Foundation	Rocky Mountain Elk Foundation encourages Applicant to continue coordination with ODFW.	Applicant acknowledges RMEF's comment and under the HMP and Juniper Treatment Plan, will continue coordinating with ODFW.

Obsidian Solar Center LLC

Obsidian Solar Center

Habitat Mitigation Plan

July ~~May~~ ~~February~~ 2020

Obsidian Solar Center LLC

5 Centerpointe Drive, Suite 250
Lake Oswego, Oregon 97035

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ATTACHMENTS

Attachment 1	~~Template~~ Working Lands Improvement Program Agreement ~~Easement~~ ~~***[Submitted Under Separate Cover]***~~
Attachment 2	Juniper Phase Mapping Technical Memo
Attachment 3	Desktop Habitat Mapping Technical Memorandum

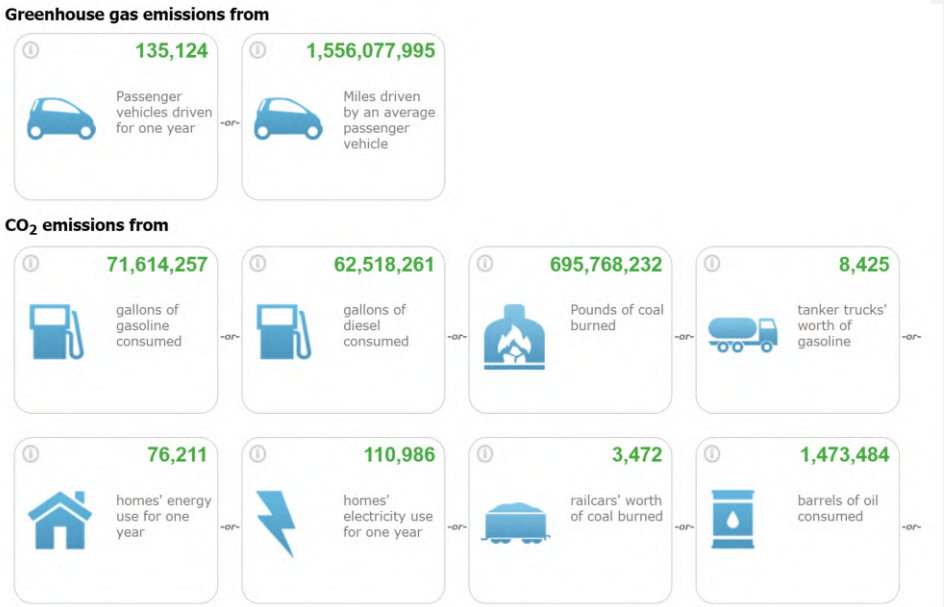
Acronyms and Abbreviations

Applicant	Obsidian Solar Center LLC
ASC	Application for Site Certificate
CWMA	Cooperative Weed Management Area
EFSC or the Council	Energy Facility Siting Council
Facility	Obsidian Solar Center
gen-tie	generation tie
HMP	Habitat Management Plan
MW	megawatts
OAR	Oregon Administrative Rule
ODFW	Oregon Department of Fish and Wildlife
ODOE	Oregon Department of Energy
OHW	ordinary high water
WLIP	Working Lands Improvement Program

1.0 INTRODUCTION

This draft Habitat Mitigation Plan ("HMP") describes how Obsidian Solar Center LLC ("Applicant") will mitigate unavoidable habitat impacts from the Obsidian Solar Center ("Facility") located in Lake County, Oregon. The purpose of the Facility is to generate renewable, clean energy that will replace, in part, energy currently generated by Northwest coal plants scheduled for closure. The Facility will operate about 30 percent of the time on a full-time equivalency basis. Applicant expects the Facility to produce about 900,000-megawatt (MW) hours per year of clean, renewable energy, which would reduce the carbon dioxide emissions equivalent to burning almost 3,500 railcars filled with coal each year (EPA 2018; Figure 1). Clean energy improvements of this kind are crucial for countering climate change, which in turn help conserve wildlife and their habitats on a landscape scale.

Figure 1. Greenhouse Gas and Carbon Dioxide Emissions Reduced Annually by the Proposed Facility



Source: EPA 2018

Habitat loss and degradation are among the greatest threats to many wildlife species around the world. Climate change also is an increasing threat to wildlife and their habitats, including to species of interest for the Facility. Research has indicated that elk (*Cervus canadensis*) (Wang et al. 2002; Sala 2006) and sagebrush habitat (Poore et al. 2009; Bradley 2010; Schrag et al. 2011) are negatively affected by climate change. Exhibit P, Section P.7.2, of the Application for Site Certificate (ASC) identifies several State Sensitive bird species in the

Facility's analysis area that are Climate Threatened or Climate Endangered, according to the National Audubon Society (2015). The Facility is a renewable energy project that will contribute to stemming climate change by reducing carbon dioxide emissions. Although the reduction in carbon emissions that will result from Facility operations may not completely counteract the loss or modification of habitat with the site boundary, it does provide a benefit to wildlife and their habitats.

This draft HMP outlines specific measures Applicant will undertake to satisfy the Oregon Energy Facility Siting Council (EFSC) Fish and Wildlife Habitat standard (Oregon Administrative Rule (OAR) 345-022-0060), which requires that the Facility, with mitigation, demonstrate consistency with the Oregon Department of Fish and Wildlife (ODFW) Habitat Mitigation Policy (OAR 635-415-0025). Applicant proposes three mitigation pathways including (1) ODFW Payment-to-Provide (Option 1), (2) a Third Party Fee-in-Lieu Program (Option 2), and (3) Working Lands Improvement Program (in-kind, in-proximity mitigation) (Option 3). Applicant opts to implement Option 3 as mitigation for the Facility. If Applicant sought to implement Option 1 or Option 2, or an ~~In addition, Applicant reserves the right to pursue~~ alternative mitigation pathways ~~if available~~ in the future, Applicant would seek ~~by pursuing~~ an amendment to this HMP, as provided under Section 6.0 below.

2.0 DESCRIPTION OF THE IMPACTS ADDRESSED BY THE HMP

The Facility is located entirely within the more than 1 million acre-area mapped by ODFW staff as elk winter range and a portion of the Facility is located within the area mapped by ODFW staff as mule deer (*Odocoileus hemionus*) winter range, which overlaps in its entirety with elk winter range (together, referred as "Big Game Winter Range"). ODFW staff has designated acres within Big Game Winter Range as Category 2 (essential and limited) habitat under ODFW's Fish and Wildlife Habitat Mitigation Policy (ODFW 2014, 2016a) ("ODFW Habitat Mitigation Policy"). ~~While Category 2 serves as the habitat category for the entire Facility, t~~The area within the site boundary consists primarily of sagebrush shrubland, with a mosaic of stand cover, plant heights, and levels of disturbance. ~~No acres of sagebrush shrubland habitat were field-characterized as Category 2 habitat, based on vegetation communities observed on-site.~~

Permanent habitat impacts will be associated primarily with the installation of permanent Facility structures. The solar array areas and related or supporting facilities will be fenced as required by electrical code and safety needs, and ODFW considers all areas inside the fence to be permanently disturbed. Temporary impacts are anticipated from the construction of the gen-tie transmission line (about 1.2 acres). Otherwise, all construction-related activities will occur within the area designated for the Facility's permanent footprint (or the area located within the perimeter fence). Temporary impacts will be fully mitigated through successful implementation of the Revegetation Plan (ASC, Appendix P-3).

The Facility will not have impacts on Category 1 habitat. The Facility will have some temporary and permanent impacts on Category 6 habitat, which do not require compensatory

mitigation.[1] For the remaining habitat types, permanent impacts must be mitigated at Category 2 under the ODFW Habitat Mitigation Policy because the impacts area is mapped Big Game Winter Range. Habitat values for Big Game Winter Range can include thermal cover, security from predation and harassment, quality forage, and limited disturbance. The area in the Facility site boundary is primarily sagebrush shrubland, and given the habitat characteristics, its primary habitat value for big game is forage and limited thermal cover.

Table 1: Acres of Temporary and Permanent Impact to Habitat within the Site Boundary

Habitat Category ~~based on Field Habitat Assessment~~	Habitat Type	Temporary Impact	Permanent Impact	Total
ODFW Designated Category 2 Habitat				
2~~3~~	Sagebrush Shrubland	0.00	3,419.21	**3,419.21**
2~~3~~	Playa OHW – Not Wetlands	0.00	16.91	**16.91**
2~~4~~	Sand Dune	0.03	108.78	**108.81**
2~~4~~	Non-sagebrush Shrubland	0.15	0.00	**0.15**
2~~5~~	Non-native Forb	0.05	42.77	**42.82**
Total Category 2 Habitat Impacts to be Mitigated		**0.23**	**3,587.67**	**3,587.90**
6	Agricultural Lands	0.56	1.00	**1.56**
6	Developed	0.21	0.00	**0.21**
	Total Impacts	**1.20**	**3,588.47**	**3,589.67**

Key:
ODFW = Oregon Department of Fish and Wildlife; OHW = Ordinary High Water

The impact analysis presented in the ASC and mitigation outlined in this HMP represents the fully built-out scenario of 400 MW. The Facility will be built as directed by market demands and power sales. For example, if Applicant enters into two separate power purchase agreements, each for 200 MW, Applicant may construct the first 200 MW and then the second 200 MW. In that case, mitigation would follow a corresponding scope and timeline.

[1] Under the ODFW Habitat Mitigation Policy, no compensatory mitigation is required for Category 6 impacts; only minimization of impacts (OAR 635-415-0025(6)).

Table 2 summarizes the habitat characteristics within the Site Boundary, as detailed in the 2018 Habitat Assessment and Biological Resources Field Report (ASC Exhibit P, Appendix P-1). Photo documentation of Area A habitat quality is also provided in photos 1-23b and 53-54 of ASC Exhibit P Appendix P-1, Attachment 1.

Table 2: Habitat Characteristics within Site Boundary

Habitat Category ~~based on Field Habitat Assessment~~	**Habitat Type**	**Native Shrub Stratum and Ground Cover**	**Native Herbaceous Stratum and Ground Cover**	**Bare Ground Cover**
ODFW Designated Category 2 Habitat				
2~~3~~	Sagebrush Shrubland	Big Sagebrush (*Artemisia tridentate)* (*15-30%)*, Green rabbitbrush (*Chrysothamnus viscidiflorus*) and Rubber rabbitbrush (*Ericameria nauseosa*) (*10-25%)*	Saltgrass (*Distichlis spicata*), Clasping pepperweed (*Lepidium perfoliatum*), and cheatgrass (*Bromus tectorum*) (≤ 25%)	40 – 60%
2~~3~~	Playa	Inclusions with Big Sagebrush (≤*2%)*, Green rabbitbrush (≤8%), and shadscale saltbrush (*Atriplex confertifolia*) (≤15%)	Usually devoid; or small areas of Saltgrass (*Distichlis spicata*) (≤25%)	≥90%
2~~4~~	Sand Dune	Big sagebrush and green rabbitbrush (<5%)	Saltgrass (*Distichlis spicata*) (<5%)	

3.0 MITIGATION OPTIONS

Applicant has identified three options for addressing the mitigation obligation where habitat protection and enhancement and/or commensurate funding are feasible and consistent with the EFSC Fish and Wildlife Standard. Based on the information provided on the record of the ASC, Applicant currently may only utilize Option 3, unless ODFW adopts appropriate regulations to support Option 1 ~~or~~ and Applicant proposes an HMP amendment to utilize Option 1 or Option 2 that EFSC ~~is~~ approves~~d~~. If other mitigation options become available or are identified, Applicant reserves the right to pursue alternative mitigation pathways by pursuing an amendment to this HMP, as provided under Section 6~~7~~.0 below.

3.1 Option 1: ODFW Payment-to-Provide

Applicant understands that ODFW is considering a payment-to-provide program that could be used to mitigate habitat impacts related to energy facilities. Applicant recognizes that

Option 1 is not available at the time of ASC review but Applicant reserves the right to use Option 1 through an HMP Amendment should it be an available ODFW program in the future. Applicant, along with other certificate holders and applicants have encouraged ODFW to adopt such a program that could be used to mitigate habitat impacts related to renewable energy projects. Such a program would help further landscape-scale mitigation projects and create greater benefits for rangeland habitat, including Big Game Winter Range habitat.

3.2 Option 2: Third Party Fee-in-Lieu Program

Under this option, Applicant would partner with EFM, Inc., an affiliate of EcoTrust. Applicant and EFM would present to Oregon Department of Energy (ODOE) and ODFW a mitigation plan designed to protect and restore habitat within the Big Game Winter Range on a portion of the about 22,000 contiguous acres west of Fort Rock currently owned and being managed by EFM, including for the benefit of mule deer. The mitigation measures that would be employed on this land are different from those outlined under Option 3 given the enhancement opportunities. Applicant presents Option 2 for discussion. Applicant may not implement Option 2 without an HMP amendment as discussed above.

3.3 Option 3: Working Lands Improvement Program (in-kind, in-proximity)

Option 3 involves habitat protection and enhancement measures on lands proximate to the Facility. Specifically, Applicant would secure land in proximity to the Facility and implement a Working Lands Improvement Program (WLIP). The WLIP is twofold: it ensures that (1) there is no net loss in quantity or quality of habitat for the life of the Facility, and (2) there is a net benefit of habitat quality for the life of the Facility. Applicant will carry out the WLIP on suitable land located two to 20 miles from the Facility and within the ODFW-mapped Big Game Winter Range. These sites are considered "in-proximity" to the Facility because the identified acres are within the home range of elk and mule deer that may also use the land within the Facility site boundary.

The WLIP is a habitat protection program and a western juniper (*Juniperus occidentalis)* treatment and management program on working rangeland. The juniper program includes juniper removal and thinning, which is consistent with the Oregon Conservation Strategy's recommended approaches for conservation of sagebrush habitats. The treatment includes controlling encroaching junipers by chipping or cutting for firewood, while maintaining pre-settlement juniper stands and juniper trees with old-age characteristics, which are important nesting habitat for birds and other wildlife (ODFW 2016b). Removal of juniper can, over time, result in redistribution of water budget components in the rangeland due to lack of tree canopy interception, in turn influencing soil moisture and vegetation. In the ODFW-mapped Big Game Winter Range, juniper removal can improve the quality and quantity of sagebrush shrubland forage while preserving effective cover habitat (such as large sagebrush and old age juniper).

Working Lands Improvement Program Agreement ~~Easements~~

Applicant will enter into enforceable and recordable Working Lands Improvement Program (WLIP) Agreements ~~working land leases~~ with the underlying property owners for land

enrolled in Applicant's WLIP. A copy ~~template~~ of the WLIP Agreement ~~working lands lease~~ is included as Attachment 1. The WLIP Agreement ~~working lands lease~~ is a legally binding agreement, authorizing Applicant to implement the WLIP consistent with this HMP and obligating the property owner to manage and operate the land consistent with the goals of the WLIP. The term of the WLIP Agreement ~~working lands lease~~ is for the life of the Facility.[2] The terms of the WLIP Agreements ~~working lands leases will~~ provide for mitigation to achieve a no net loss of habitat quality or quantity. The implementation of the juniper treatment and management program on lands subject to WLIP Agreements ~~working lands leases will~~ achieve mitigation results in a net benefit of habitat quality. Applicant will provide copies of the executed WLIP Agreements ~~working lands leases~~ to ODOE prior to construction of the Facility.

WLIP Sites

Applicant performed a juniper phase desktop analysis of about 22,722 acres of land in Big Game Winter Range near the Facility site. The desktop analysis identified juniper woodland succession phases (Phase 1, Phase 2, Phase 3) and provided mapping of the phases as well as areas unsuitable for mitigation (*e.g.*, lava beds or quarries).[3] See Attachment 2. From this information, Applicant identified two property owners with large tracts of land for participation in the WLIP: the Morrison Ranch at about 1,870 acres and the Nine Peaks Ranch at about 4,500 acres, totaling about 6,370 acres.[4] Applicant conducted a preliminary desktop

[2] "For the life of the Facility" is defined at the point when EFSC terminates the site certificate pursuant to OAR 345-027-0010. Before EFSC terminates a site certificate, the certificate holder must apply to EFSC to terminate the site certificate and provide EFSC with a proposed retirement plan consistent with OAR 345-027-0110(5), which requires, among other things, the information about how certificate holder will address impacts to wildlife and the environment during retirement. Before certificate holder may take action, EFSC must review the proposed final retirement plan, considered comments from the public and reviewing agencies, approved the proposed final requirement plan, and issued an order authorizing the retirement according to the approved final retirement plan, as provided for in OAR 345-027-0010. The approved final retirement plan will require certificate holder to restore the site and ODFW may comment on the retirement plan to ensure that the Facility continues to meet the ODFW Mitigation Policy "for the life of the Facility." EFSC may not terminate the site certificate until EFSC finds that certificate holder has completed retirement according to EFSC order authorizing retirement. See OAR 345-027-0110(8).

[3] The desktop analysis was conducted according to the protocols in the *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Circular 1321*, Miller et al. (2007).

[4] The GIS data show the Morrison Ranch and Nine Peaks Ranch mitigation area acreage as slightly larger than the tax lot acres. The GIS data show the Nine Acres Ranch mitigation area

assessment of habitat types and categories on the about 6,370 acres to confirm that the habitat is of similar structure and function as the habitat within the Facility site boundary. See Attachment 3 for the desktop habitat mapping.

The Morrison Ranch mitigation area is located, at its closest point, about 2 miles north of the Facility site boundary. This mitigation area is within the ODFW-mapped Big Game Winter Range and has about 970 acres of sagebrush shrubland and 960 acres of juniper woodland. The sagebrush shrubland within this mitigation area has similar habitat structure and function to the sagebrush shrubland within the Facility site boundary. Roughly, half of the juniper woodlands in the Morrison Ranch mitigation area are Phase 2 succession and likely support an understory with levels of sagebrush and perennial bunchgrasses that are suitable for restoration or conversion to sagebrush shrubland. The Phase 3 succession areas, which is also about half of the juniper woodland habitat in this mitigation area, may also exhibit restoration potential. The Morrison Ranch mitigation area also provides primary habitat values for big game, such as forage and thermal cover. Therefore, this land represents in-kind habitat for purposes of meeting Applicant's Category 2 habitat mitigation obligations.

The Nine Peaks Ranch mitigation area is located, at its closest point, about 7 miles north of the Facility site boundary. This mitigation area is within the ODFW-mapped Big Game Winter Range and has about 4,225 of sagebrush shrubland and 330 acres of juniper woodland. Sagebrush shrubland at Nine Peaks Ranch would be similar in structure and function as the sagebrush shrubland within the Facility site boundary; however, almost 85 percent of sagebrush shrubland in this mitigation area exhibits Phase 1 juniper encroachment. Phase 1 encroachment areas are in danger, long term, of further juniper succession, and would be great candidates for juniper restoration. The Nine Peaks Ranch mitigation area also provides primary habitat values for big game, such as forage and thermal cover. Therefore, this land represents in-kind habitat for purposes of meeting Applicant's Category 2 habitat mitigation obligations.

~~Prior to construction of the Facility~~In addition, Applicant ~~will~~ conducted field-based habitat mapping of the WLIP sites, based on a protocol approved by ODOE, in consultation with ODFW (consistent with the field-based habitat mapping performed for the field surveys conducted as a part of Exhibit P). ~~Applicant will provide t~~The resulting written report of a survey and mapping ~~to ODOE and ODFW~~ attached as Attachment 4 and provided to ODFW on or about May 22, 2020, demonstrate ~~to verify~~ that selected mitigation acres within the Morrison Ranch and the Nine Peaks Ranch are "in-kind" habitat to meet the Facility's mitigation obligations under this HMP.

Once ODOE, in consultation with ODFW, ~~has concurred~~ concurs with Applicant's field verifications, Applicant will execute WLIP Agreements ~~working lands leases~~ substantially in the form attached as Attachment 1 with the Morrison Ranch and/or the Nine Peaks Ranch.

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at about 4,595 acres and the Morrison Ranch mitigation area at about 1,939 acres, rather than 4,500 and 1,870 acres, respectively.

Land under control ~~lease~~ will total 1.2~~1~~ acres for every 1 acre of habitat impacted by the Facility components.

Implementation of the WLIP for Habitat Enhancement

Applicant will implement the WLIP across acreage totaling 1.2 acres for every 1 acre of habitat permanently impacted by the Facility components based on final Facility design. For example, if the final Facility footprint is 3,588 acres, Applicant will protect 4,~~.~~306 acres of habitat from development and conduct the habitat enhancement measures across the 4,306 acres, as described below. ~~The WLIP includes the following components[5]:~~

Step 1: Pre-Treatment Juniper Survey

Applicant ~~will~~ conducted a pre-treatment survey to determine the appropriate j~~J~~uniper t~~T~~reatment areas ~~Unit, facilitate preparation of the applicable Juniper Treatment Plan for that Unit,~~ and record pre-treatment conditions (the "Pre-Treatment Survey"). The Pre-Treatment survey ~~will also~~ informed the Juniper Treatment Plans. ~~The Pre-Treatment Survey may occur as part of, or concurrently with, the pre-construction field-based habitat assessment of the WLIP sites (as described above).~~ The Pre-Treatment Survey ~~will~~ was ~~be~~ conducted in accordance with a protocol, ~~to be~~ submitted and approved by ODFW, based on the methods included in the *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Survey Circular 1321* (Miller et al, 2007). ~~The Pre-Treatment Survey will document dominant plant species within each habitat type, including general habitat conditions, such as tree and shrub heights and cover (including presence of pre-settlement junipers), weed species and coverage, and level of disturbance. Applicant shall provide the results of the Pre-Treatment Survey to ODOE and ODFW.~~

~~Applicant will use the desktop analysis and field-based habitat/weed surveys, in consultation with its qualified consultants, to identify Juniper Treatment Units within the WLIP sites. The Juniper Treatment Units may vary in size depending on natural landscape divisions, qualities, prior uses, etc. and the treatment schedule for different Juniper Treatment Units may vary.[6]~~

Step 2: Develop Juniper Treatment Plan

~~Prior to construction of the Facility, following completion of the Pre-Treatment Habitat/Weed Surveys,~~ Applicant ~~will~~ has developed and submitted for review and approval to ODOE, in consultation with ODFW, ~~a~~ juniper treatment ~~plan or~~ plans ~~depending on the areas selected~~

~~[6] As stated in the ASC, Applicant will develop the Facility based on market demands and other factors. This means that construction may occur in steps or on a rolling basis. Mitigation for each step of construction or implementation of rolling mitigation would correspond to the rolling construction.~~

for treatment within the WLIP sites.~~site specific Juniper Treatment Plan(s). A Juniper Treatment Plan, Aat a minimum, t~~The plans ~~will~~ include the following components:

- Habitat maps identifying the boundary of proposed ~~Juniper Treatment Unit within WLIP site and~~ treatment areas.

- A description and figures ~~table~~ identifying approximate acres of treatment areas by treatment type~~application per treatment plan for the Juniper Treatment Unit (*e.g.*, xx acres for thinning, xx acres for juniper removal, xx acres for protection of juniper stands)~~.

- Best management practices to minimize the risk of noxious weed introduction into juniper treatment areas including equipment wash out station, reseeding of burned slash treatment piles with a grass/legume mix (within 30 days of the fire), and monitoring burned areas for noxious weeds (annually for three years following reseeding).

- A protocol establishing methods for documentation of pre- and post-treatment conditions such as through photo documentation; and, field based methods including walking a representative sample of 100-meter random transects to assess soil disturbance and vegetation conditions (plant cover, native herbaceous cover, non-native cover).

- Recommendations for post-treatment monitoring, weed treatment, and juniper re-treatment.

~~A Juniper Treatment Plan may correspond to one or more designated mitigation units within the WLIP sites. Mitigation work must commence within the same season or year of the correlative Facility construction commencement, based on final Facility design and construction schedule at that time. Following construction completion, Applicant may adjust the mitigation obligation (site size, extent of juniper treatment) if changes in final Facility design during construction occur that reduce the mitigation obligation.~~

Step 3: Juniper Treatment

~~Applicant~~ Certificate holder will hire one or more contractors (locally, to the extent possible) to implement the Juniper Treatment Plan(s) across the WLIP sites. Depending on the local site conditions and the capabilities of the contractor(s), felled juniper may be burned on site or hauled away. If slash burning is to occur, contractor will obtain necessary burn permits and will coordinate with landowners, as applicable. Juniper may also be sorted and decked, delimbed, and any commercial product taken off site. ~~Juniper Treatment Plans will emphasize retaining pre-settlement juniper (or late successional junipers) and removing young juniper encroaching into pre-settlement juniper stands as well as other young juniper within the treatment area. The methods for juniper removal will vary depending in local site conditions. One method would be to hand cut and hand pile the trees. Another would be to pull the mid-sized juniper with a rubber tire tractor or small excavator and hand cut the large and very small post-settlement juniper; all juniper would be mechanically piled~~. In

implementing t~~T~~he Juniper Treatment Plans, Certificate holder will direct the cutting contractor to minimize impacts to sagebrush in the understory.

Step 4: Weed Monitoring and Treatment

Applicant will engage the Lake County Cooperative Weed Management Area (Lake County CWMA) or other qualified contractor to monitor the WLIP sites for noxious weeds. Lake County CWMA (or qualified contractor) will monitor noxious weeds within a treated area annually for two years ~~Juniper Treatment Unit within 12 months and again within the following 12 months~~ after initial juniper treatment and Lake County CWMA will treat weeds as needed during the monitoring. ~~-~~In addition, Lake County CMWA will monitor burned slash treatment pile areas annually for ~~in year~~ 3 years following reseeding and will treat weeds as needed during the monitoring. Applicant will provide copies of the annual weed monitoring and treatment reports to ODOE and ODFW. Thereafter, Lake County CWMA(or other qualified contractor) will monitor and treat noxious weeds in the WLIP sites as described below.

Step 5: Monitoring and Reporting

Applicant will hire a qualified contractor to conduct monitoring in the treated areas ~~of each Juniper Treatment Unit~~ and provides reports to ODOE, ODFW, and Lake County as provided for in the applicable Juniper Treatment Plans. The monitoring program will consist of monitoring for noxious weeds as well as monitoring for mitigation success.

Generally, the first post-treatment monitoring for mitigation success will occur within one year ~~begin about 24 months~~ after the initial j~~J~~uniper t~~T~~reatment is completed and continue every ~~seven~~ ten years thereafter for the life of the Facility. Polygons where no treatment is planned will be monitored when neighboring polygons with a common boundary are scheduled for treatment or monitoring. For those areas that have been seeded following disturbance, monitoring will include collection of the following information:

- Confirmation that all disturbance areas requiring active re-vegetation have been re-seeded;
- Visual estimates of:
  - Percental of total vegetative ground dover of individual plant species in two categories (grasses/forbs and shrubs), and
  - Percentage bare soil
- Presence of noxious weeds species (including density and geographical extent of populations); and

- Presence of windblow or water erosion problems that require additional measures.

More generally, m~~M~~onitoring measures to be documented include:

- Confirm ongoing compliance with WLIP ~~leases~~agreements;
- Assess changes in vegetation cover (species, structural stage, health)~~), and progress towards meeting success criteria, including the presence or lack of noxious weeds~~;
- Document environmental factors such as average rainfall, average snowfall, occurrence of wildfire, etc.; and
- Assess juniper encroachment to evaluate whether retreatment may be needed, using the location points identified during the initial Juniper Treatment.

Prior to construction of the Facility, Applicant shall provide a draft report template for review and comment by ODOE, in consultation with ODFW. Based on the agency-reviewed report template, Applicant will provide ODOE and ODFW a report following each monitoring period detailing the observations and results, including the details of any noxious weed treatment and juniper retreatment.

The monitoring reports will document remedial actions take to date, additional remedial actions planned for areas that are not apparently trending toward success, and the anticipated dates of completion of each of these actions. Remedial actions may include additional juniper treatments (as described below in Section 4.0; Juniper Encroachment), weed treatment, and re-seeding, to correct deficiencies or shortcomings. Remedial actions will be implemented as needed. The nature of the remedial action will depend on the specific issues that arise.

Commented [MS1]: Added and revised for consistency with Juniper Treatment Plan and Revegetation and Weed Control Plan.

Commented [MS2]: Added for consistency with Appendix P-3.

4.0 SUCCESS CRITERIA

Given the Facility's location in ODFW-mapped Big Game Winter Range, Applicant must meet Category 2 mitigation goal of "no net loss of either habitat quantity or quality and to provide a net benefit of habitat quantity or quality." The mitigation measures presented in this draft HMP ensure that the Facility's permanent and temporary impacts will not result in a net loss of habitat quantity or quality and result in a net benefit of habitat quality. Applicant will measure success during its monitoring periods and success will be based on the following indicators:

- Juniper Encroachment. Because juniper will be left in most of the polygons, some amount of juniper encroachment will occur in the forage polygons within the life of the Facility. A juniper treatment will be considered successful if encroachment does not exceed 10 stems per acre over a majority of the treatment area as determined by the monitoring described in the Juniper Treatment Plan. When the results of monitoring indicate that juniper encroachment has exceeded 10 stems/acre over a

majority of a polygon then encroaching juniper will be cut using treatment 1 as described in the Juniper Treatment Plan.

- ~~Increase in herbaceous cover within the WLIP treatment areas, compared to reference sites, based on soil characteristics, precipitation regimes, native plant association prior to juniper encroachment, historical fire regime, and desired future condition using *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Circular 1321*, Miller et al. (2007);~~

- ~~Maintenance of a specified percent juniper overstory within the Juniper Treatment Areas (to be specified in the applicable Juniper Treatment Plan after the Pre-Treatment Survey has been completed);~~

- ~~Response of sage brush and/or bitter brush as measured by the leader growth in the cut areas within a Juniper Treatment Unit compared to areas without cutting in the Juniper Treatment Unit; and~~

- Successful weed control (weed monitoring and treatment) within the WLIP sites for the life of the Facility. The success criteria for noxious weed control will be based on qualitative observations to attempt to comply with Lake County and ODA recommended actions in each category of noxious weed. Consistent with Applicant's Revegetation and Noxious Weed Control Plan (Appendix P-3), unless otherwise instructed to use other criteria by ODA or Lake County, Applicant will consider weed control successful when State- or County-listed noxious weeds are absent or constitute less than 1 percent of vegetation otherwise dominated by native or desirable non-native species, unless the noxious weeds present are similar to pre-disturbance conditions or adjacent undisturbed areas.

~~Success criteria may be further refined in the Juniper Treatment Plans depending on Applicant's juniper contractor recommendations, the Pre-Treatment Survey, and other site-specific conditions for the treatment area within the WLIP. Applicant is mitigating primarily for impacts to sagebrush shrubland, which was preliminarily identified as Category 3 habitat based on vegetative characteristics observed during field habitat assessments, but was designated as Category 2 because of the ODFW-mapped Big Game Winter Range overlay. As a result, habitat within the WLIP sites will only need to be enhanced to the extent it provides the quality of habitat impacted by the Facility.~~

Commented [MS3]: Change for consistency with Juniper Treatment Plan and Revegetation and Weed Control Plan (Appendix P-3)

Commented [MS4]: Newly added to be consistent with Juniper Treatment Plan and Appendix P-3.

5.0 PRE-CONSTRUCTION COMPLIANCE

The final HMP applies to the entirety of permanent and temporary Category 2 habitat impacts.[7] This draft HMP contains ~~numerous~~ pre-construction requirements to which Applicant must comply. As described throughout this plan, prior to construction of the Facility, Applicant shall:

- ~~Develop and submit a habitat assessment protocol for the Facility site boundary and the WLIP sites for review and approval by ODOE in consultation with ODFW;~~\
- Identify the total number of permanent and temporary habitat acres to be impacted, based on permanent facility components within the perimeter fence line and temporary impacts outside of the fence line, including any important assumptions or calculations;
- Executed WLIP Agreements~~landowner agreements~~, with an opportunity for review and concurrence by ODOE if agreements contain termination or amendment clauses;
- Finalize ~~Draft~~ Juniper Treatment Plan(s) ~~(for the Juniper Treatment Units commensurate in size to the initial construction area),~~ including maps of treatment areas; treatment plans and methods, pre- and post-documentation protocols, monitoring and reporting protocols.

6.0 AMEMDMENTS TO THE HMP

The HMP may be amended from time to time upon approval by EFSC, who may delegate its authority to review and authorize amendments to ODOE. ODOE must notify EFSC of all amendments and EFSC retains the authority to approve, reject, or modify any amendments to this HMP agreed to by ODOE.

[7] Applicant began construction in 2019 on two solar projects located on land within the Facility site boundary under Lake County Permit No. 19-027-CUP and Lake County Permit No. 19-028-CUP. Applicant is implementing mitigation measures for each project under the respective CUP approvals. Applicant will terminate Lake County Permit No. 19-027-CUP and Lake County Permit No. 19-028-CUP once Applicant has demonstrated compliance with the Facility site certificate's pre-construction conditions of approval, at which point the solar development previously approved under the County CUPs will become subject to EFSC jurisdiction. Applicant proposes a condition of approval requiring an HMP status report to ODOE prior to construction confirming that mitigation conducted under the two county permits meets and will continue to meet the mitigation requirements under this HMP.

7.0 REFERENCES

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Fosters Natural Resource Contracting

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Michelle Slater 7 July, 2020
Obsidian Solar Center LLC
5 Centerpointe Drive, Suite 250
Lake Oswego, OR
97035

Michelle,

As requested, the information below provides a summary of information available on the natural history of mice and rats common to the Northern Great Basin. We provide conclusions regarding the potential dispersal of deer mice due to disturbance caused by development of the Obsidian Solar Center.

Common Species:

- Deer Mice (*Peromyscus maniculatus*)
- Sagebrush Vole (*Lemmiscus curtatus*)
- Kangaroo rats and mice (*Dipodomys spp.*)
- Wood rats (*Neotoma spp.*)

Population densities and abundance are completely dependent on weather, habitat quality (i.e. the amount of food and cover available) and predator densities. The other species are either less abundant or generally not associated with disturbed habitats common to farmed or developed agricultural areas, although wood rats commonly cause property damage. The most severe agricultural damage caused by mice and rats is reduced value of stored cereal grains. Other common impacts are 1.) the negative effect caused by them living in and defecating on stacked hay, equipment and buildings. 2.) their propensity to chew on and destroy electrical wiring. 3.) the potential to spread infectious diseases to humans and pets. Deer mice are the most abundant rodent in agricultural areas and for the rest of this discussion we will use them as the species of most concern.

Deer Mice:

Life Span outside captivity: Most deer mice live less than 1 year. It is common for adults to live 1 to 2 years. Juveniles have 60-80% mortality rates each month. Adults 30-50%.

Home Range: Size increases as habitat quality decreases. Size range: 242m^2 (0.06 acres) – 3000 m^2 (0.74 acres).

Dispersal: Increases with amount of disturbance. In non-disturbed habitats dispersal is generally less than 500 feet. In an area of Kansas prairie burned annually under 7 different

fire prescriptions over a 15-year period, dispersal ranged from 49m (160 feet) to 779m (2555 feet, ~0.5 miles).

Population Densities: Range from 1-25 mice/ha (2.5 – 63/acre) with one report of 400 mice/acre under exceptional conditions. Densities fluctuate dependent on predator densities, weather and habitat quality. Exponential population increases or decreases are common. Radical increases generally occur in the summer and almost always trigger a predator response which results in the increase lasting less than 6 months.

Breeding Season and Birth Rate: In the Northern Great Basin breeding season is generally March to October. Juveniles are sexually mature at 2 months of age. Females have one litter approximately every 30 days during the breeding season. Litter size is 3-5 young.

Conclusions:

Based on the research available disturbance as a result of development of the solar center may result in a temporary increase in mice due to dispersal into areas within 160 feet to maybe 0.5 miles from the development. The increase would only be radical if the population was exceptionally high during the period of disturbance. An increase in predation and competition between rodents for available resources would result in the population returning to pre-disturbance levels within 6 months.

The proposed area of the solar center is approximately 6 square miles (3921 acres). Obsidian is proposing a rolling construction plan for development of the solar center. A significant amount (> 50%) of the rodent dispersal due to disturbance will be to undisturbed or revegetated locations within the solar center, and not to neighboring properties.

Sincerely,

Craig Foster

Oregon Department
of Fish & Wildlife

Statewide

General Season Antlerless Elk Damage tag

December 19, 2019

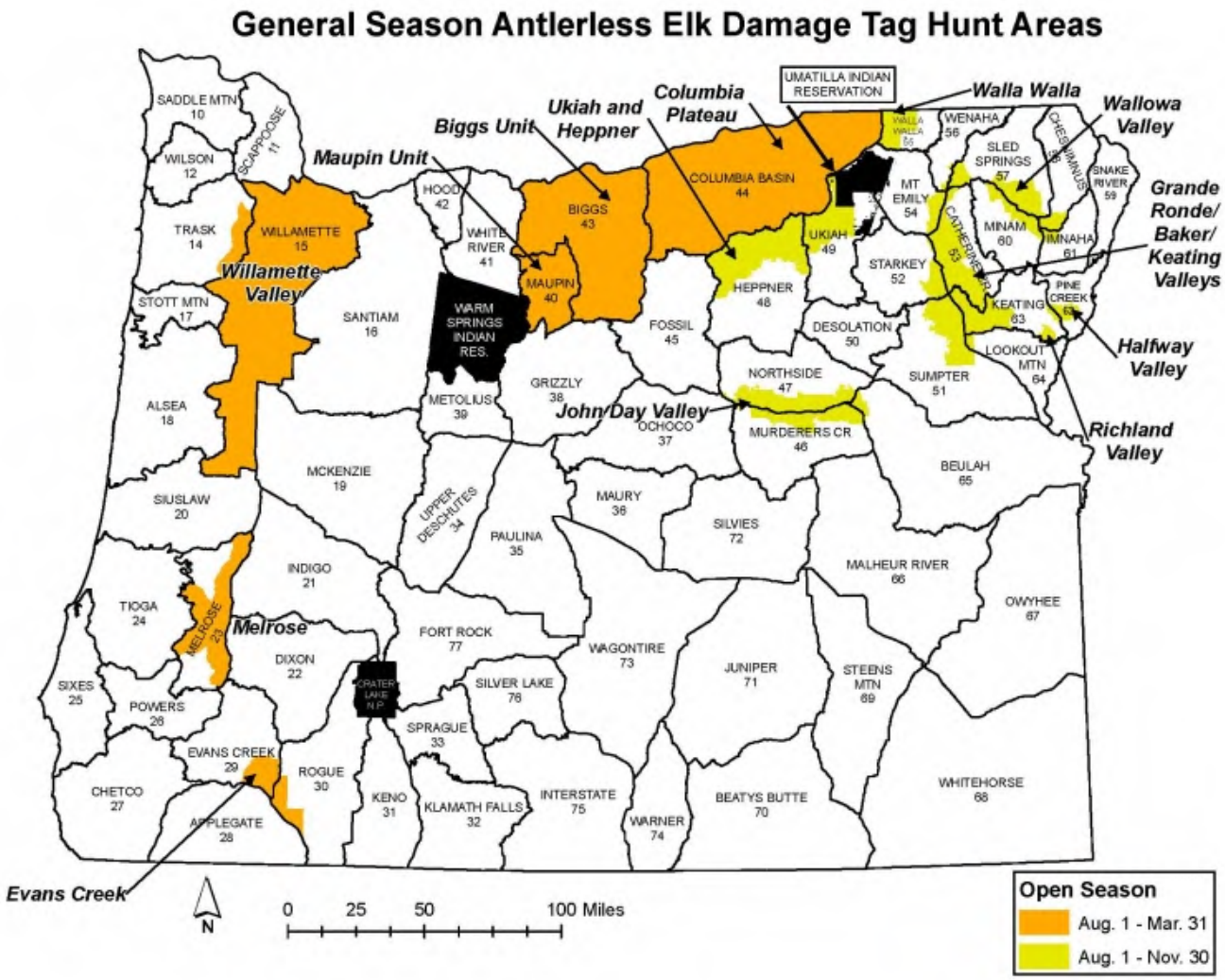
Due to increasing numbers of elk on private land and chronic elk damage, ODFW is piloting a new general season elk damage tag

In a nutshell:

- These tags are a hunter's only elk hunting opportunity for the year, and cannot be used in addition to other general season or controlled elk hunt tags.
- These over-the-counter tags can be purchased throughout the hunting season.
- Tags may be used in any of the hunt areas shown on the map below.
- The vast majority of these hunts are on private land. Do not purchase a tag unless you already have access to a place to hunt.
- Bag limit is one antlerless elk.

The new General Season Antlerless Elk Damage tag is a new approach to using hunting as management tool in areas of chronic elk damage. The general season antlerless elk damage tag replaces 19 controlled hunts and will replace the need for Landowner Damage Program tags in the areas and during the time periods of the hunts.

These hunts are a tool for hunters and landowners to **directly work together** to reduce elk damage. The hunt areas are nearly 100 percent private, largely agricultural lands. ODFW staff will not be able to assist you with finding a place to hunt. Elk numbers are highly variable within the hunt areas as many of the areas are designated as elk de-emphasis areas.



Hunt area maps (GeoPDFs*)

*GeoPDFs can display location, mark way points, and check boundaries using a smartphone or tablet even when offline when using apps such as Avenza Maps or Paper Maps.

- Biggs WMU (view map)
- Columbia Plateau WMU (view map)
- Evans Creek (view map)
- Grande Ronde/Baker/Keating – north (view map)
- Grande Ronde/Baker/Keating – south (view map)
- Halfway Valley (view map)
- John Day (view map)
- Maupin WMU (view map)
- Melrose (view map)
- Richland Valley (view map)
- Ukiah/Heppner (view map)
- Walla Walla (view map)
- Wallowa Valley (view map)
- Willamette Valley – north (view map)
  - Trask Portion (North) of the Willamette Valley Hunt - (view map)
  - Trask Portion (South) of the Willamette Valley Hunt - (view map)

- Willamette Valley – south (view map)

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Oregon Department of Fish and Wildlife

Elk Damage on Private Land

Senate and House
Natural Resource Committees
March 28, 2019

State of Oregon Wildlife Policy (ORS 496.012)

…wildlife shall be managed to prevent serious depletion … and to provide optimum recreational and aesthetic benefits

<u>Coequal goals of wildlife management:</u>

- **Optimum population levels**
- **Develop and manage lands & waters for production and public enjoyment of wildlife**
- **Orderly and equitable utilization**
- **Public access**
- **<u>Compatible with primary uses of the land</u>**
- **Optimum recreational benefits**
- **Decisions for social, economic & recreational use**

Legislative Assembly Findings on Wildlife Damage (ORS 610.055)

… appropriate measures must be taken to assist farmers, ranchers and others in resolving wildlife damage problems.

Department Wildlife Damage Policy:

- Advice / Repellents
- Hazing
- Barriers / Fencing
- Habitat Programs
  - Regional Habitat Biologists
  - Green Forage
  - Access and Habitat Projects
- Harvest Management

Harvest Management

Hunting Seasons:

- For large scale take of elk
- Used for population control or reduction
- Can be a localized area or several wildlife units

Landowner Preference Tags:

- Used for both recreation and damage control during hunting seasons

Oregon Landowner Damage Program:

- Allows issuance of tags for landowner's property
- Allows landowner to pick who receives a tag
- Can customize hunt dates
- No limit on tags other than no more than 5 at a time
- Very popular with landowner community

Harvest Management (continued)

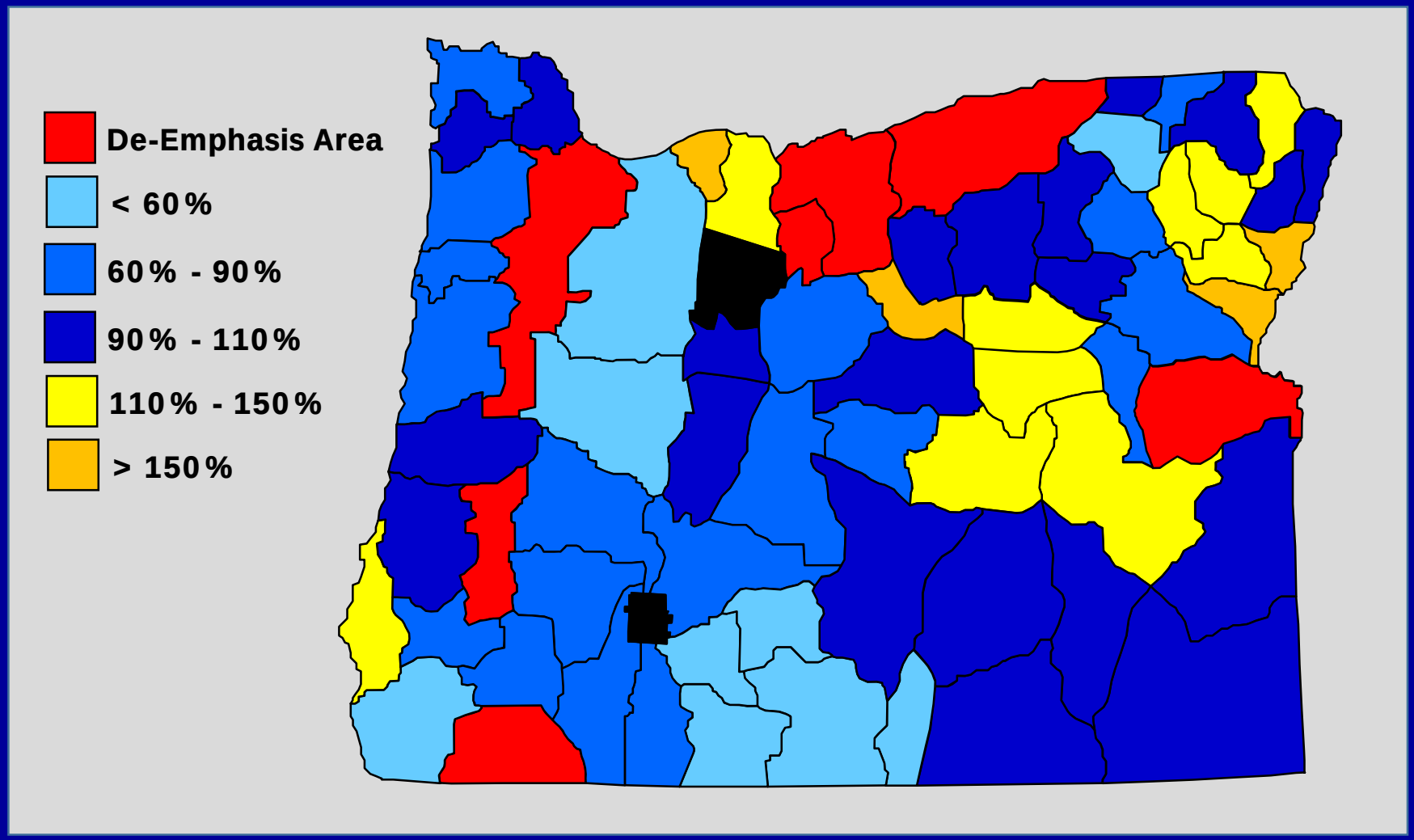
Emergency Hunts:

- Use of hunters to take animals in damage situations
- Can customize dates or hunt areas
- Can combine multiple landowners
- Hunters taken off a list; landowner does not control who receives a tag

Kill permits:

- Specific tool with limited utility
- Best in situations where take of one or a few animals will solve damage
- Can be used 24 hours a day
- May be best if take is necessary in area with safety concerns

Percent of Elk Population Objective by Wildlife Management Unit in 2018



Questions?

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TARDAEWETHER Kellen * ODOE

From: Albrich, Elaine <ElaineAlbrich@dwt.com>
Sent: Monday, July 20, 2020 4:22 PM
To: TARDAEWETHER Kellen * ODOE; REIF Sarah J
Cc: Michelle Slater; ESTERSON Sarah * ODOE; WOODS Maxwell * ODOE; DONALD Erin L; MUIR Jonathan D; David Brown; Albrich, Elaine
Subject: Obsidian Solar Center - Response to ODFW Comments (7/16/2020 letter)
Attachments: Obsidian__Attachment 1_OSC_habitat_mitigation_plan_022120_final_revised_05142020 and 07142020 and 072020.docx; WLIP Agreement_redline in response to ODFW 7-16-20 comments.docx; Obsidian_Response to ODFW Comment Letter 07162020.docx

Hi –

Please see Obsidian's response to ODFW's comment letter dated July 16, 2020. Also provided are the revised HMP (new revisions noted in redline and green highlight) and the WLIP Agreement (new revisions noted in redline) in response to ODFW's comments. I'm providing to ODFW at the same time for the sake of efficiency in light of tonight's DPO hearing.

Thank you everyone – Elaine

Elaine R. Albrich
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July 20, 2020

VIA EMAIL

Kellen Tardaewether
Senior Siting Analyst
Oregon Department of Energy
550 Capitol Street NE
Salem, OR 97301

Re: Obsidian Solar Center's Response to ODFW Comment Letter, July 16, 2020

Dear Kellen:

On behalf of Obsidian Solar Center LLC ("Applicant"), please find our response to the July 16, 2020 letter from Oregon Department of Fish and Wildlife ("ODFW") ("July ODFW Letter") commenting on Applicant's May 22, 2020 Draft Working Lands Improvement Program (WLIP) Agreement ("WLIP Agreement"). The July ODFW Letter is in addition to letters from ODFW dated April 24, 2020, May 18, 2020, and June 11, 2020. These four letters outline the steps Applicant and ODFW have taken to narrow the unresolved items from the Habitat Mitigation Plan ("HMP"), Juniper Treatment Plan, and the Revegetation and Noxious Weed Control Plan. The July ODFW Letter appears to identify ODFW's last remaining comments, which are limited to the WLIP Agreement.

Many of the ODFW comments are already addressed by language in the WLIP Agreement or can be readily resolved with some additional language to reiterate real estate fundamentals and operations of law between the HMP and WLIP Agreement (i.e., a binding, recorded real property agreement). Big picture, the WLIP Agreement clearly lays out the intent of the parties for the agreement to run with the land, which is all that is required to do. The agreement does not need to be called a "conservation easement" in order to contain restrictive covenants that bind the landowner and run with the land. *See* Restatement (Third) of Property: Servitudes, § 3.1-3.2 (Am. Law Inst. 2000). Additionally, ODFW and ODOE, as intended third-party beneficiaries of the WLIP Agreement and third-party beneficiaries are entitled to enforce agreements, which should provide ODFW further comfort that the mitigation will be carried out. *See Nordbye v. BRCP/GM Ellington*, 246 Or App 209, 266 P3d 92 (2011), *rev den*, 352 Or 33 (2012). Principles of real estate law are clear – what is essential for an agreement to run with the land is the *intent* of the parties. Oregon Real Estate Deskbook (2015 Edition), at § 13.2. Here, the intent of the parties to the WLIP is clear: the recorded WLIP Agreement will be enforceable by ODFW for

the life of the project. As described below, this is reinforced in the WLIP Agreement text and in the HMP.

July ODFW Letter, Bullet 1

ODFW suggests ODOE incorporate provisions of the WLIP Agreement into the HMP in order to give EFSC a direct link to enforce the Applicant's proposed mitigation.

Response: Once EFSC approves a site certificate, the certificate holder becomes obligated to comply with the Construction and Operation Rules for Facilities in OAR chapter 345, division 26. These rules provide broad authority for EFSC enforcement over facility construction and operation and provide mechanisms to ensure that certificate holder is complying with its obligations under the site certificate. OAR 345-026-0048 requires certificate holder to implement a plan that verifies compliance with all site certificate terms and conditions. OAR 345-026-0050 requires a certificate holder to allow members of EFSC or ODOE to inspect the facility during construction, operation and retirement. The rule also provides that if an ODOE inspector finds a violation, such findings must be reported to EFSC at its next scheduled meeting and responsive action is required. Further, OAR 345-026-105 requires that the certificate holder and ODOE exchange copies of all correspondence related to compliance, which includes correspondence with other state agencies so there are already mechanisms in place to ensure ongoing coordination with certificate holder, ODOE, and ODFW.

Compliance with the HMP is mandatory because compliance is required by DPO Recommended FWH Condition 2. Further, the HMP requires that Applicant enter into and remain in good standing under the WLIP Agreements. While Applicant believes this intent is already clear in the HMP, Applicant proposes revisions to address ODFW's concern (see HMP, Section 3.3, Working Lands Improvement Program Agreement, p 5-6 green highlight). Finally, OAR 345-026-0048 to OAR 345-026-0170 provide the rules by which EFSC and ODOE enforce and monitor compliance. Nothing further is needed to address ODFW's comment.

July ODFW Letter, Bullet 2

ODFW suggests adding enforcement language to the WLIP Agreement and HMP that requires periodic visits by ODOE (and ODFW by extension).[1]

Response: Section 7 of the WLIP Agreement already grants ODOE and ODFW (explicitly) a limited right of access to the property upon reasonable written notice to inspect the mitigation

[1] In both Bullet 1 and Bullet 2, ODFW uses the phrase "solid nexus" when arguing for a particular revision. It is unclear whether ODFW is arguing for a particular legal standard for demonstrating compliance. In any event, Applicant maintains that the level of specificity ODFW is attempting to impose in the HMP and WLIP Agreement are not required by ODOE rules or ODFW rules and ODFW cannot continue to interpret its rules on a case by case basis.

work. Applicant intentionally added this language in response to earlier comments from ODOE and ODFW about wanting to ensure access for compliance purposes. Applicant proposes adding additional language to Section 3.3, Implementation of the WLIP, Step 5 Monitoring and Reporting (p 10-11 green highlight).

July ODFW Letter, Bullet 3

ODFW suggests including language in the HMP about not only entering into the WLIP Agreement but that it will be maintained through the life of the project.

Response: The HMP requires Applicant to enter into the WLIP Agreements, a form of which is attached to the HMP. The WLIP Agreement has a 30-year term and may be renewed for five 5 periods to ensure that the agreement covers the life of the project. The HMP requires implementation of Option 3 for the life of the project. Therefore, it is clear on the face of both the HMP and the WLIP Agreement that Applicant is obligated to maintain the WLIP Agreement for the life of the project. The HMP already provides that the "term of the WLIP Agreement is for the life of the Facility." See HMP, Section 3.3, Working Lands Improvement Program Agreement paragraph (p. 5-6 green highlighted language). Applicant proposes a further revision to Section 2 of the WLIP Agreement to reflect the intent that the WLIP Agreement is for the life of the Facility.

July ODFW Letter, Bullet 4

In the event the mitigation property transfers ownership, HMP should require Obsidian give notice to ODOE and enter into new agreement with the landowner. * * *

Response: The WLIP Agreement is binding on all successors and assigns of the mitigation landowner and will be recorded in the real property records of Lake County to provide notice to any potential purchasers that the property comes subject to the WLIP Agreement. A form of the memorandum of agreement is included as an exhibit to the WLIP Agreement to illustrate the notice that will be available on title. By operation of law, the WLIP Agreement runs with the land. Section 4 of the WLIP Agreement specifies the binding language of the agreement and says explicitly that if the property owner sells the property, it does so subject to the term and conditions of the WLIP Agreement. Obsidian must also be notified in writing in the case of such transfer. ODFW's concern that "it will be difficult to find willing landowners" is misplaced and not going to happen – there will be no "time gaps" in mitigation as ODFW seems to imply.

<u>July ODFW Letter, Bullet 5</u>

ODFW suggests attaching the final HMP to the WLIP Agreement.

<u>Response</u>: Applicant proposes to include the final HMP as Exhibit D to the WLIP Agreement. See revision to Section 5 of the WLIP Agreement.

<u>July ODFW Letter, Bullet 6</u>

Improve the list of allowable and prohibited uses in the WLIP and include as conditions in the HMP.

<u>Response:</u> Applicant does not understand ODFW's comment because Section 5(a) and (b) of the WLIP Agreement expressly state that all nonagricultural activities, unless otherwise identified in the WLIP Agreement, are prohibited – this means that all commercial, industrial, and agri-tourism activities (including those uses mentioned in the July ODFW Letter) are prohibited. We think a more effective drafting technique is to specify what is allowed and prohibited anything that is not otherwise specified. Applicant objects to removing passive recreation and hunting from the WLIP Agreement as these privileges are important to the landowners and removing these privileges could jeopardize a landowner's willingness to participate in the WLIP. Further, passive recreation like hiking and hunting are not inconsistent with the HMP goals, which focus on projecting the mitigation property from future development and enhancing habitat for big game forage cover. With respect to quiet enjoyment, Section 17 of the WLIP Agreement has the landowner granting Obsidian the right of quiet use and enjoyment to further project Obsidian's efforts in carrying out the HMP objectives.

<u>July ODFW Letter, Bullet 7</u>

For allowable uses, exclude landowner's desired buildable areas from the WLIP lease area.

<u>Response:</u> Existing development and up to 5 acres of future development are included in the WLIP Agreement in order to give Applicant control over landowner's use of these areas but the areas are not counted towards the mitigation acreage. These areas can be identified on the baseline inventory (see response below).

<u>July ODFW Letter, Bullet 8</u>

Improve baseline information to confirm baseline for existing development and grazing practices. * * *

<u>Response</u>: See new language in Section 5(d) to respond to ODFW's comment.

In closing, thank you for your ongoing work on this project. We hope that these responses resolve the last of ODFW's comments on the HMP and implementing documents. Applicant appreciates ODOE and ODFW's ongoing work towards resolving outstanding items in the draft documents to help ensure that Applicant can move quickly to construction following site certificate approval.

Very truly yours

Davis Wright Tremaine LLP

Elaine R. Albrich

Elaine R. Albrich

cc: David W. Brown
Michelle Slater

Obsidian Solar Center LLC

Obsidian Solar Center

Habitat Mitigation Plan

July ~~May~~ ~~February~~ 2020

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4823-0346-2083v.1 0110562-000001~~4823-0346-2083v.1 0110562-000001~~~~4852-2816-4803v.1 0110562-000001~~

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ATTACHMENTS

Attachment 1	~~Template~~ Working Lands Improvement Program Agreement ~~Easement~~ ~~***[Submitted Under Separate Cover]***~~
Attachment 2	Juniper Phase Mapping Technical Memo
Attachment 3	Desktop Habitat Mapping Technical Memorandum

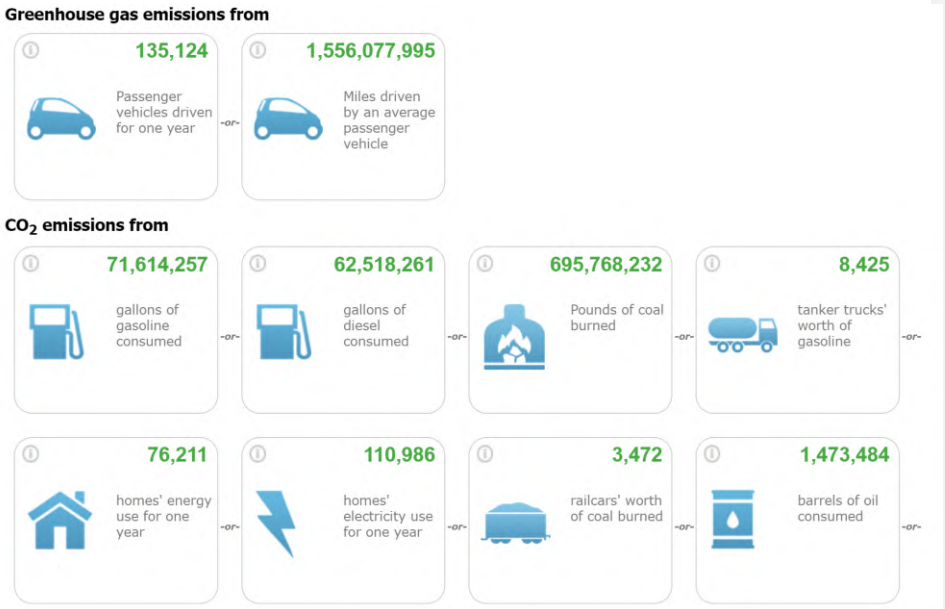
Acronyms and Abbreviations

Applicant	Obsidian Solar Center LLC
ASC	Application for Site Certificate
CWMA	Cooperative Weed Management Area
EFSC or the Council	Energy Facility Siting Council
Facility	Obsidian Solar Center
gen-tie	generation tie
HMP	Habitat Management Plan
MW	megawatts
OAR	Oregon Administrative Rule
ODFW	Oregon Department of Fish and Wildlife
ODOE	Oregon Department of Energy
OHW	ordinary high water
WLIP	Working Lands Improvement Program

1.0 INTRODUCTION

This draft Habitat Mitigation Plan ("HMP") describes how Obsidian Solar Center LLC ("Applicant") will mitigate unavoidable habitat impacts from the Obsidian Solar Center ("Facility") located in Lake County, Oregon. The purpose of the Facility is to generate renewable, clean energy that will replace, in part, energy currently generated by Northwest coal plants scheduled for closure. The Facility will operate about 30 percent of the time on a full-time equivalency basis. Applicant expects the Facility to produce about 900,000-megawatt (MW) hours per year of clean, renewable energy, which would reduce the carbon dioxide emissions equivalent to burning almost 3,500 railcars filled with coal each year (EPA 2018; Figure 1). Clean energy improvements of this kind are crucial for countering climate change, which in turn help conserve wildlife and their habitats on a landscape scale.

Figure 1. Greenhouse Gas and Carbon Dioxide Emissions Reduced Annually by the Proposed Facility



Source: EPA 2018

Habitat loss and degradation are among the greatest threats to many wildlife species around the world. Climate change also is an increasing threat to wildlife and their habitats, including to species of interest for the Facility. Research has indicated that elk (*Cervus canadensis*) (Wang et al. 2002; Sala 2006) and sagebrush habitat (Poore et al. 2009; Bradley 2010; Schrag et al. 2011) are negatively affected by climate change. Exhibit P, Section P.7.2, of the Application for Site Certificate (ASC) identifies several State Sensitive bird species in the

Facility's analysis area that are Climate Threatened or Climate Endangered, according to the National Audubon Society (2015). The Facility is a renewable energy project that will contribute to stemming climate change by reducing carbon dioxide emissions. Although the reduction in carbon emissions that will result from Facility operations may not completely counteract the loss or modification of habitat with the site boundary, it does provide a benefit to wildlife and their habitats.

This draft HMP outlines specific measures Applicant will undertake to satisfy the Oregon Energy Facility Siting Council (EFSC) Fish and Wildlife Habitat standard (Oregon Administrative Rule (OAR) 345-022-0060), which requires that the Facility, with mitigation, demonstrate consistency with the Oregon Department of Fish and Wildlife (ODFW) Habitat Mitigation Policy (OAR 635-415-0025). Applicant proposes three mitigation pathways including (1) ODFW Payment-to-Provide (Option 1), (2) a Third Party Fee-in-Lieu Program (Option 2), and (3) Working Lands Improvement Program (in-kind, in-proximity mitigation) (Option 3). Applicant opts to implement Option 3 as mitigation for the Facility. If Applicant sought to implement Option 1 or Option 2, or an ~~In addition, Applicant reserves the right to pursue~~ alternative mitigation pathways ~~if available~~ in the future, Applicant would seek ~~by pursuing~~ an amendment to this HMP, as provided under Section 6.0 below.

2.0 DESCRIPTION OF THE IMPACTS ADDRESSED BY THE HMP

The Facility is located entirely within the more than 1 million acre-area mapped by ODFW staff as elk winter range and a portion of the Facility is located within the area mapped by ODFW staff as mule deer (*Odocoileus hemionus*) winter range, which overlaps in its entirety with elk winter range (together, referred as "Big Game Winter Range"). ODFW staff has designated acres within Big Game Winter Range as Category 2 (essential and limited) habitat under ODFW's Fish and Wildlife Habitat Mitigation Policy (ODFW 2014, 2016a) ("ODFW Habitat Mitigation Policy"). ~~While Category 2 serves as the habitat category for the entire Facility, t~~The area within the site boundary consists primarily of sagebrush shrubland, with a mosaic of stand cover, plant heights, and levels of disturbance. ~~No acres of sagebrush shrubland habitat were field-characterized as Category 2 habitat, based on vegetation communities observed on-site.~~

Permanent habitat impacts will be associated primarily with the installation of permanent Facility structures. The solar array areas and related or supporting facilities will be fenced as required by electrical code and safety needs, and ODFW considers all areas inside the fence to be permanently disturbed. Temporary impacts are anticipated from the construction of the gen-tie transmission line (about 1.2 acres). Otherwise, all construction-related activities will occur within the area designated for the Facility's permanent footprint (or the area located within the perimeter fence). Temporary impacts will be fully mitigated through successful implementation of the Revegetation Plan (ASC, Appendix P-3).

The Facility will not have impacts on Category 1 habitat. The Facility will have some temporary and permanent impacts on Category 6 habitat, which do not require compensatory

mitigation.[1] For the remaining habitat types, permanent impacts must be mitigated at Category 2 under the ODFW Habitat Mitigation Policy because the impacts area is mapped Big Game Winter Range. Habitat values for Big Game Winter Range can include thermal cover, security from predation and harassment, quality forage, and limited disturbance. The area in the Facility site boundary is primarily sagebrush shrubland, and given the habitat characteristics, its primary habitat value for big game is forage and limited thermal cover.

Table 1: Acres of Temporary and Permanent Impact to Habitat within the Site Boundary

Habitat Category ~~based on Field Habitat Assessment~~	**Habitat Type**	**Temporary Impact**	**Permanent Impact**	**Total**
ODFW Designated Category 2 Habitat				
2~~3~~	Sagebrush Shrubland	0.00	3,419.21	**3,419.21**
2~~3~~	Playa OHW – Not Wetlands	0.00	16.91	**16.91**
2~~4~~	Sand Dune	0.03	108.78	**108.81**
2~~4~~	Non-sagebrush Shrubland	0.15	0.00	**0.15**
2~~5~~	Non-native Forb	0.05	42.77	**42.82**
Total Category 2 Habitat Impacts to be Mitigated		**0.23**	**3,587.67**	**3,587.90**
6	Agricultural Lands	0.56	1.00	**1.56**
6	Developed	0.21	0.00	**0.21**
	Total Impacts	**1.20**	**3,588.47**	**3,589.67**

Key:
ODFW = Oregon Department of Fish and Wildlife; OHW = Ordinary High Water

The impact analysis presented in the ASC and mitigation outlined in this HMP represents the fully built-out scenario of 400 MW. The Facility will be built as directed by market demands and power sales. For example, if Applicant enters into two separate power purchase agreements, each for 200 MW, Applicant may construct the first 200 MW and then the second 200 MW. In that case, mitigation would follow a corresponding scope and timeline.

[1] Under the ODFW Habitat Mitigation Policy, no compensatory mitigation is required for Category 6 impacts; only minimization of impacts (OAR 635-415-0025(6)).

Table 2 summarizes the habitat characteristics within the Site Boundary, as detailed in the 2018 Habitat Assessment and Biological Resources Field Report (ASC Exhibit P, Appendix P-1). Photo documentation of Area A habitat quality is also provided in photos 1-23b and 53-54 of ASC Exhibit P Appendix P-1, Attachment 1.

Table 2: Habitat Characteristics within Site Boundary

Habitat Category ~~based on Field Habitat Assessment~~	**Habitat Type**	**Native Shrub Stratum and Ground Cover**	**Native Herbaceous Stratum and Ground Cover**	**Bare Ground Cover**
ODFW Designated Category 2 Habitat				
2~~3~~	Sagebrush Shrubland	Big Sagebrush (*Artemisia tridentate)* (*15-30%)*, Green rabbitbrush (*Chrysothamnus viscidiflorus*) and Rubber rabbitbrush (*Ericameria nauseosa*) (*10-25%)*	Saltgrass (*Distichlis spicata*), Clasping pepperweed (*Lepidium perfoliatum*), and cheatgrass (*Bromus tectorum*) (≤ 25%)	40 – 60%
2~~3~~	Playa	Inclusions with Big Sagebrush (≤*2%)*, Green rabbitbrush (≤8%), and shadscale saltbrush (*Atriplex confertifolia*) (≤15%)	Usually devoid; or small areas of Saltgrass (*Distichlis spicata*) (≤25%)	≥90%
2~~4~~	Sand Dune	Big sagebrush and green rabbitbrush (<5%)	Saltgrass (*Distichlis spicata*) (<5%)	

3.0 MITIGATION OPTIONS

Applicant has identified three options for addressing the mitigation obligation where habitat protection and enhancement and/or commensurate funding are feasible and consistent with the EFSC Fish and Wildlife Standard. Based on the information provided on the record of the ASC, Applicant currently may only utilize Option 3, unless ODFW adopts appropriate regulations to support Option 1 ~~or~~ and Applicant proposes an HMP amendment to utilize Option 1 or Option 2 that EFSC ~~is~~ approves~~d~~. If other mitigation options become available or are identified, Applicant reserves the right to pursue alternative mitigation pathways by pursuing an amendment to this HMP, as provided under Section 6~~7~~.0 below.

3.1 Option 1: ODFW Payment-to-Provide

Applicant understands that ODFW is considering a payment-to-provide program that could be used to mitigate habitat impacts related to energy facilities. Applicant recognizes that

Option 1 is not available at the time of ASC review but Applicant reserves the right to use Option 1 through an HMP Amendment should it be an available ODFW program in the future. Applicant, along with other certificate holders and applicants have encouraged ODFW to adopt such a program that could be used to mitigate habitat impacts related to renewable energy projects. Such a program would help further landscape-scale mitigation projects and create greater benefits for rangeland habitat, including Big Game Winter Range habitat.

3.2 Option 2: Third Party Fee-in-Lieu Program

Under this option, Applicant would partner with EFM, Inc., an affiliate of EcoTrust. Applicant and EFM would present to Oregon Department of Energy (ODOE) and ODFW a mitigation plan designed to protect and restore habitat within the Big Game Winter Range on a portion of the about 22,000 contiguous acres west of Fort Rock currently owned and being managed by EFM, including for the benefit of mule deer. The mitigation measures that would be employed on this land are different from those outlined under Option 3 given the enhancement opportunities. Applicant presents Option 2 for discussion. Applicant may not implement Option 2 without an HMP amendment as discussed above.

3.3 Option 3: Working Lands Improvement Program (in-kind, in-proximity)

Option 3 involves habitat protection and enhancement measures on lands proximate to the Facility. Specifically, Applicant would secure land in proximity to the Facility and implement a Working Lands Improvement Program (WLIP). The WLIP is twofold: it ensures that (1) there is no net loss in quantity or quality of habitat for the life of the Facility, and (2) there is a net benefit of habitat quality for the life of the Facility. Applicant will carry out the WLIP on suitable land located two to 20 miles from the Facility and within the ODFW-mapped Big Game Winter Range. These sites are considered "in-proximity" to the Facility because the identified acres are within the home range of elk and mule deer that may also use the land within the Facility site boundary.

The WLIP is a habitat protection program and a western juniper (*Juniperus occidentalis)* treatment and management program on working rangeland. The juniper program includes juniper removal and thinning, which is consistent with the Oregon Conservation Strategy's recommended approaches for conservation of sagebrush habitats. The treatment includes controlling encroaching junipers by chipping or cutting for firewood, while maintaining pre-settlement juniper stands and juniper trees with old-age characteristics, which are important nesting habitat for birds and other wildlife (ODFW 2016b). Removal of juniper can, over time, result in redistribution of water budget components in the rangeland due to lack of tree canopy interception, in turn influencing soil moisture and vegetation. In the ODFW-mapped Big Game Winter Range, juniper removal can improve the quality and quantity of sagebrush shrubland forage while preserving effective cover habitat (such as large sagebrush and old age juniper).

Working Lands Improvement Program Agreement ~~Easements~~

Applicant will enter into enforceable and recordable Working Lands Improvement Program (WLIP) Agreements ~~working land leases~~ with the underlying property owners for land

enrolled in Applicant's WLIP. A copy ~~template~~ of the WLIP Agreement ~~working lands lease~~ is included as Attachment 1. The WLIP Agreement ~~working lands lease~~ is a legally binding agreement, authorizing Applicant to implement the WLIP consistent with this HMP and obligating the property owner to manage and operate the land consistent with the goals of the WLIP. The term of the WLIP Agreement ~~working lands lease~~ is for the life of the Facility.[2] The terms of the WLIP Agreements ~~working lands leases will~~ provide for mitigation to achieve a no net loss of habitat quality or quantity. The implementation of the juniper treatment and management program on lands subject to WLIP Agreements ~~working lands leases will~~ achieve mitigation results in a net benefit of habitat quality. Applicant will provide copies of the executed WLIP Agreements ~~working lands leases~~ to ODOE prior to construction of the Facility. Applicant is obligated to maintain in good standing under the WLIP Agreement for the life of the Facility.

WLIP Sites

Applicant performed a juniper phase desktop analysis of about 22,722 acres of land in Big Game Winter Range near the Facility site. The desktop analysis identified juniper woodland succession phases (Phase 1, Phase 2, Phase 3) and provided mapping of the phases as well as areas unsuitable for mitigation (*e.g.*, lava beds or quarries).[3] See Attachment 2. From this information, Applicant identified two property owners with large tracts of land for participation in the WLIP: the Morrison Ranch at about 1,870 acres and the Nine Peaks Ranch

[2] "For the life of the Facility" is defined at the point when EFSC terminates the site certificate pursuant to OAR 345-027-0010. Before EFSC terminates a site certificate, the certificate holder must apply to EFSC to terminate the site certificate and provide EFSC with a proposed retirement plan consistent with OAR 345-027-0110(5), which requires, among other things, the information about how certificate holder will address impacts to wildlife and the environment during retirement. Before certificate holder may take action, EFSC must review the proposed final retirement plan, considered comments from the public and reviewing agencies, approved the proposed final requirement plan, and issued an order authorizing the retirement according to the approved final retirement plan, as provided for in OAR 345-027-0010. The approved final retirement plan will require certificate holder to restore the site and ODFW may comment on the retirement plan to ensure that the Facility continues to meet the ODFW Mitigation Policy "for the life of the Facility." EFSC may not terminate the site certificate until EFSC finds that certificate holder has completed retirement according to EFSC order authorizing retirement. See OAR 345-027-0110(8).

[3] The desktop analysis was conducted according to the protocols in the *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Circular 1321*, Miller et al. (2007).

at about 4,500 acres, totaling about 6,370 acres.[4] Applicant conducted a preliminary desktop assessment of habitat types and categories on the about 6,370 acres to confirm that the habitat is of similar structure and function as the habitat within the Facility site boundary. See Attachment 3 for the desktop habitat mapping.

The Morrison Ranch mitigation area is located, at its closest point, about 2 miles north of the Facility site boundary. This mitigation area is within the ODFW-mapped Big Game Winter Range and has about 970 acres of sagebrush shrubland and 960 acres of juniper woodland. The sagebrush shrubland within this mitigation area has similar habitat structure and function to the sagebrush shrubland within the Facility site boundary. Roughly, half of the juniper woodlands in the Morrison Ranch mitigation area are Phase 2 succession and likely support an understory with levels of sagebrush and perennial bunchgrasses that are suitable for restoration or conversion to sagebrush shrubland. The Phase 3 succession areas, which is also about half of the juniper woodland habitat in this mitigation area, may also exhibit restoration potential. The Morrison Ranch mitigation area also provides primary habitat values for big game, such as forage and thermal cover. Therefore, this land represents in-kind habitat for purposes of meeting Applicant's Category 2 habitat mitigation obligations.

The Nine Peaks Ranch mitigation area is located, at its closest point, about 7 miles north of the Facility site boundary. This mitigation area is within the ODFW-mapped Big Game Winter Range and has about 4,225 of sagebrush shrubland and 330 acres of juniper woodland. Sagebrush shrubland at Nine Peaks Ranch would be similar in structure and function as the sagebrush shrubland within the Facility site boundary; however, almost 85 percent of sagebrush shrubland in this mitigation area exhibits Phase 1 juniper encroachment. Phase 1 encroachment areas are in danger, long term, of further juniper succession, and would be great candidates for juniper restoration. The Nine Peaks Ranch mitigation area also provides primary habitat values for big game, such as forage and thermal cover. Therefore, this land represents in-kind habitat for purposes of meeting Applicant's Category 2 habitat mitigation obligations.

~~Prior to construction of the Facility~~In addition, Applicant ~~will~~ conducted field-based habitat mapping of the WLIP sites, based on a protocol approved by ODOE, in consultation with ODFW (consistent with the field-based habitat mapping performed for the field surveys conducted as a part of Exhibit P). ~~Applicant will provide t~~The resulting written report of a survey and mapping ~~to ODOE and ODFW~~ attached as Attachment 4 and provided to ODFW on or about May 22, 2020, demonstrate ~~to verify~~ that selected mitigation acres within the

[4] The GIS data show the Morrison Ranch and Nine Peaks Ranch mitigation area acreage as slightly larger than the tax lot acres. The GIS data show the Nine Acres Ranch mitigation area at about 4,595 acres and the Morrison Ranch mitigation area at about 1,939 acres, rather than 4,500 and 1,870 acres, respectively.

Morrison Ranch and the Nine Peaks Ranch are "in-kind" habitat to meet the Facility's mitigation obligations under this HMP.

Once ODOE, in consultation with ODFW, ~~has concurred~~ concurs with Applicant's field verifications, Applicant will execute WLIP Agreements ~~working lands leases~~ substantially in the form attached as Attachment 1 with the Morrison Ranch and/or the Nine Peaks Ranch. Land under control ~~lease~~ will total 1.2~~1~~ acres for every 1 acre of habitat impacted by the Facility components.

Implementation of the WLIP for Habitat Enhancement

Applicant will implement the WLIP across acreage totaling 1.2 acres for every 1 acre of habitat permanently impacted by the Facility components based on final Facility design. For example, if the final Facility footprint is 3,588 acres, Applicant will protect 4,~~.~~306 acres of habitat from development and conduct the habitat enhancement measures across the 4,306 acres, as described below. ~~The WLIP includes the following components[5]:~~

Step 1: Pre-Treatment Juniper Survey

Applicant ~~will~~ conducted a pre-treatment survey to determine the appropriate j~~J~~uniper t~~T~~reatment areas ~~Unit, facilitate preparation of the applicable Juniper Treatment Plan for that Unit,~~ and record pre-treatment conditions (the "Pre-Treatment Survey"). The Pre-Treatment survey ~~will also~~ informed the Juniper Treatment Plans. ~~The Pre-Treatment Survey may occur as part of, or concurrently with, the pre-construction field-based habitat assessment of the WLIP sites (as described above).~~ The Pre-Treatment Survey ~~will~~ was ~~be~~ conducted in accordance with a protocol, ~~to be~~ submitted and approved by ODFW, based on the methods included in the *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Survey Circular 1321* (Miller et al, 2007). ~~The Pre-Treatment Survey will document dominant plant species within each habitat type, including general habitat conditions, such as tree and shrub heights and cover (including presence of pre-settlement junipers), weed species and coverage, and level of disturbance. Applicant shall provide the results of the Pre-Treatment Survey to ODOE and ODFW.~~

~~Applicant will use the desktop analysis and field-based habitat/weed surveys, in consultation with its qualified consultants, to identify Juniper Treatment Units within the WLIP sites. The Juniper Treatment Units may vary in size depending on natural landscape divisions, qualities, prior uses, etc. and the treatment schedule for different Juniper Treatment Units may vary.[6]~~

~~[6] As stated in the ASC, Applicant will develop the Facility based on market demands and other factors. This means that construction may occur in steps or on a rolling basis. Mitigation for each step of construction or implementation of rolling mitigation would correspond to the rolling construction.~~

Step 2: Develop Juniper Treatment Plan

~~Prior to construction of the Facility, following completion of the Pre-Treatment Habitat/Weed Surveys,~~ Applicant ~~will~~ has developed and submitted for review and approval to ODOE, in consultation with ODFW, ~~a~~ juniper treatment ~~plan or~~ plans ~~depending on the areas selected~~ for treatment within the WLIP sites.~~site specific Juniper Treatment Plan(s). A Juniper Treatment Plan, Aat a minimum, t~~The plans ~~will~~ include the following components:

- Habitat maps identifying the boundary of proposed ~~Juniper Treatment Unit within WLIP site and~~ treatment areas.

- A description and figures ~~table~~ identifying approximate acres of treatment areas by treatment type~~application per treatment plan for the Juniper Treatment Unit (*e.g.*, xx acres for thinning, xx acres for juniper removal, xx acres for protection of juniper stands)~~.

- Best management practices to minimize the risk of noxious weed introduction into juniper treatment areas including equipment wash out station, reseeding of burned slash treatment piles with a grass/legume mix (within 30 days of the fire), and monitoring burned areas for noxious weeds (annually for three years following reseeding).

- A protocol establishing methods for documentation of pre- and post-treatment conditions such as through photo documentation; and, field based methods including walking a representative sample of 100-meter random transects to assess soil disturbance and vegetation conditions (plant cover, native herbaceous cover, non-native cover).

- Recommendations for post-treatment monitoring, weed treatment, and juniper re-treatment.

~~A Juniper Treatment Plan may correspond to one or more designated mitigation units within the WLIP sites. Mitigation work must commence within the same season or year of the correlative Facility construction commencement, based on final Facility design and construction schedule at that time. Following construction completion, Applicant may adjust the mitigation obligation (site size, extent of juniper treatment) if changes in final Facility design during construction occur that reduce the mitigation obligation.~~

Step 3: Juniper Treatment

~~Applicant~~ Certificate holder will hire one or more contractors (locally, to the extent possible) to implement the Juniper Treatment Plan(s) across the WLIP sites. Depending on the local site conditions and the capabilities of the contractor(s), felled juniper may be burned on site or hauled away. If slash burning is to occur, contractor will obtain necessary burn permits and will coordinate with landowners, as applicable. Juniper may also be sorted and decked, delimbed, and any commercial product taken off site. ~~Juniper Treatment Plans will emphasize retaining pre-settlement juniper (or late successional junipers) and removing young~~

~~juniper encroaching into pre-settlement juniper stands as well as other young juniper within the treatment area. The methods for juniper removal will vary depending in local site conditions. One method would be to hand cut and hand pile the trees. Another would be to pull the mid-sized juniper with a rubber tire tractor or small excavator and hand cut the large and very small post-settlement juniper; all juniper would be mechanically piled~~. In implementing t~~T~~he Juniper Treatment Plans, Certificate holder will direct the cutting contractor to minimize impacts to sagebrush in the understory.

Step 4: Weed Monitoring and Treatment

Applicant will engage the Lake County Cooperative Weed Management Area (Lake County CWMA) or other qualified contractor to monitor the WLIP sites for noxious weeds. Lake County CWMA (or qualified contractor) will monitor noxious weeds within a treated area annually for two years ~~Juniper Treatment Unit within 12 months and again within the following 12 months~~ after initial juniper treatment and Lake County CWMA will treat weeds as needed during the monitoring. ~~-~~In addition, Lake County CMWA will monitor burned slash treatment pile areas annually for ~~in year~~ 3 years following reseeding and will treat weeds as needed during the monitoring. Applicant will provide copies of the annual weed monitoring and treatment reports to ODOE and ODFW. Thereafter, Lake County CWMA(or other qualified contractor) will monitor and treat noxious weeds in the WLIP sites as described below.

Step 5: Monitoring and Reporting

Applicant will hire a qualified contractor to conduct monitoring in the treated areas ~~of each Juniper Treatment Unit~~ and provides reports to ODOE, ODFW, and Lake County as provided for in the applicable Juniper Treatment Plans. The monitoring program will consist of monitoring for noxious weeds as well as monitoring for mitigation success.

Generally, the first post-treatment monitoring for mitigation success will occur within one year ~~begin about 24 months~~ after the initial j~~J~~uniper t~~T~~reatment is completed and continue every ~~seven~~ ten years thereafter for the life of the Facility. Polygons where no treatment is planned will be monitored when neighboring polygons with a common boundary are scheduled for treatment or monitoring. For those areas that have been seeded following disturbance, monitoring will include collection of the following information:

- Confirmation that all disturbance areas requiring active re-vegetation have been re-seeded;
- Visual estimates of:
  - Percental of total vegetative ground dover of individual plant species in two categories (grasses/forbs and shrubs), and

- Percentage bare soil

- Presence of noxious weeds species (including density and geographical extent of populations); and

- Presence of windblow or water erosion problems that require additional measures.

More generally, m~~M~~onitoring measures to be documented include:

- Confirm ongoing compliance with WLIP ~~leases~~agreements;

- Assess changes in vegetation cover (species, structural stage, health)~~), and progress towards meeting success criteria, including the presence or lack of noxious weeds~~;

- Document environmental factors such as average rainfall, average snowfall, occurrence of wildfire, etc.; and

- Assess juniper encroachment to evaluate whether retreatment may be needed, using the location points identified during the initial Juniper Treatment.

Prior to construction of the Facility, Applicant shall provide a draft report template for review and comment by ODOE, in consultation with ODFW. Based on the agency-reviewed report template, Applicant will provide ODOE and ODFW a report following each monitoring period detailing the observations and results, including the details of any noxious weed treatment and juniper retreatment.

In addition to reporting, ODOE has authority to conduct inspections pursuant to OAR 345-026-0050 to ensure that WLIP is being carried out consistent with the HMP. The WLIP Agreement grants ODOE and ODFW limited access rights for inspections with reasonable written notice to the Property Owner and Applicant.

The monitoring reports will document remedial actions take to date, additional remedial actions planned for areas that are not apparently trending toward success, and the anticipated dates of completion of each of these actions. Remedial actions may include additional juniper treatments (as described below in Section 4.0; Juniper Encroachment), weed treatment, and re-seeding, to correct deficiencies or shortcomings. Remedial actions will be implemented as needed. The nature of the remedial action will depend on the specific issues that arise.

Commented [MS1]: Added and revised for consistency with Juniper Treatment Plan and Revegetation and Weed Control Plan.

Commented [MS2]: Added for consistency with Appendix P-3.

4.0 SUCCESS CRITERIA

Given the Facility's location in ODFW-mapped Big Game Winter Range, Applicant must meet Category 2 mitigation goal of "no net loss of either habitat quantity or quality and to provide a net benefit of habitat quantity or quality." The mitigation measures presented in this draft HMP ensure that the Facility's permanent and temporary impacts will not result in a net loss of habitat quantity or quality and result in a net benefit of habitat quality. Applicant will

measure success during its monitoring periods and success will be based on the following indicators:

- Juniper Encroachment. Because juniper will be left in most of the polygons, some amount of juniper encroachment will occur in the forage polygons within the life of the Facility. A juniper treatment will be considered successful if encroachment does not exceed 10 stems per acre over a majority of the treatment area as determined by the monitoring described in the Juniper Treatment Plan. When the results of monitoring indicate that juniper encroachment has exceeded 10 stems/acre over a majority of a polygon then encroaching juniper will be cut using treatment 1 as described in the Juniper Treatment Plan.

- ~~Increase in herbaceous cover within the WLIP treatment areas, compared to reference sites, based on soil characteristics, precipitation regimes, native plant association prior to juniper encroachment, historical fire regime, and desired future condition using *Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions: U.S. Geological Circular 1321*, Miller et al. (2007);~~

- ~~Maintenance of a specified percent juniper overstory within the Juniper Treatment Areas (to be specified in the applicable Juniper Treatment Plan after the Pre-Treatment Survey has been completed);~~

- ~~Response of sage brush and/or bitter brush as measured by the leader growth in the cut areas within a Juniper Treatment Unit compared to areas without cutting in the Juniper Treatment Unit; and~~

- Successful weed control (weed monitoring and treatment) within the WLIP sites for the life of the Facility. The success criteria for noxious weed control will be based on qualitative observations to attempt to comply with Lake County and ODA recommended actions in each category of noxious weed. Consistent with Applicant's Revegetation and Noxious Weed Control Plan (Appendix P-3), unless otherwise instructed to use other criteria by ODA or Lake County, Applicant will consider weed control successful when State- or County-listed noxious weeds are absent or constitute less than 1 percent of vegetation otherwise dominated by native or desirable non-native species, unless the noxious weeds present are similar to pre-disturbance conditions or adjacent undisturbed areas.

Commented [MS3]: Change for consistency with Juniper Treatment Plan and Revegetation and Weed Control Plan (Appendix P-3)

Commented [MS4]: Newly added to be consistent with Juniper Treatment Plan and Appendix P-3.

~~Success criteria may be further refined in the Juniper Treatment Plans depending on Applicant's juniper contractor recommendations, the Pre-Treatment Survey, and other site-specific conditions for the treatment area within the WLIP. Applicant is mitigating primarily for impacts to sagebrush shrubland, which was preliminarily identified as Category 3 habitat based on vegetative characteristics observed during field habitat assessments, but was designated as Category 2 because of the ODFW-mapped Big Game Winter Range overlay. As a result, habitat within the WLIP sites will only need to be enhanced to the extent it provides the quality of habitat impacted by the Facility.~~

5.0 PRE-CONSTRUCTION COMPLIANCE

The final HMP applies to the entirety of permanent and temporary Category 2 habitat impacts.[7] This draft HMP contains ~~numerous~~ pre-construction requirements to which Applicant must comply. As described throughout this plan, prior to construction of the Facility, Applicant shall:

- ~~Develop and submit a habitat assessment protocol for the Facility site boundary and the WLIP sites for review and approval by ODOE in consultation with ODFW;~~\
- Identify the total number of permanent and temporary habitat acres to be impacted, based on permanent facility components within the perimeter fence line and temporary impacts outside of the fence line, including any important assumptions or calculations;
- Executed WLIP Agreements~~landowner agreements~~, with an opportunity for review and concurrence by ODOE if agreements contain termination or amendment clauses;
- Finalize ~~Draft~~ Juniper Treatment Plan(s) ~~(for the Juniper Treatment Units commensurate in size to the initial construction area),~~ including maps of treatment areas; treatment plans and methods, pre- and post-documentation protocols, monitoring and reporting protocols.

6.0 AMEMDMENTS TO THE HMP

The HMP may be amended from time to time upon approval by EFSC, who may delegate its authority to review and authorize amendments to ODOE. ODOE must notify EFSC of all amendments and EFSC retains the authority to approve, reject, or modify any amendments to this HMP agreed to by ODOE.

---

[7] Applicant began construction in 2019 on two solar projects located on land within the Facility site boundary under Lake County Permit No. 19-027-CUP and Lake County Permit No. 19-028-CUP. Applicant is implementing mitigation measures for each project under the respective CUP approvals. Applicant will terminate Lake County Permit No. 19-027-CUP and Lake County Permit No. 19-028-CUP once Applicant has demonstrated compliance with the Facility site certificate's pre-construction conditions of approval, at which point the solar development previously approved under the County CUPs will become subject to EFSC jurisdiction. Applicant proposes a condition of approval requiring an HMP status report to ODOE prior to construction confirming that mitigation conducted under the two county permits meets and will continue to meet the mitigation requirements under this HMP.

7.0 REFERENCES

Bradley, B. A. 2010. Assessing Ecosystem Threats from Global and Regional Change: Hierarchical Modeling of Risk to Sagebrush Ecosystems from Climate Change, Land Use and Invasive Species in Nevada, USA. *Ecography*, *33*(1), 198-208.

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WORKING LANDS IMPROVEMENT AGREEMENT

This Working Lands Improvement Agreement ("Agreement") is entered into this _____day of_____, 2020, ("Effective Date"), between _____, ("Property Owner"), and Obsidian Solar Center, LLC, an Oregon limited liability company ("Obsidian").

Recitals

A. Obsidian is developing a solar photovoltaic energy facility on approximately 3,900 acres of rangeland in northern Lake County, Oregon ("Facility").

B. The Facility is subject to review and approval by the Oregon Energy Facility Siting Council ("EFSC"). As a part of the EFSC permitting process, Obsidian is required to develop a Habitat Mitigation Plan ("HMP") to mitigate for impacts to habitat, including area mapped by the Oregon Department of Fish and Wildlife ("ODFW") as big game winter range.

C. The HMP requires Obsidian to secure land in proximity to the Facility and implement the mitigation measures described in the HMP, which include a Working Lands Improvement Program ("WLIP"). The WLIP is a western juniper (*Juniperus occidentalis*) treatment and management program on working rangeland and involves juniper removal and thinning, controlling encroaching junipers by chipping or cutting for firewood, and maintaining pre-settlement juniper stands and juniper trees with old-age characteristics, which are important nesting habitat for birds and other wildlife.

D. The purpose of the WLIP is to ensure that there is no net loss in quantity or quality of habitat for the life of the Facility and there is a net benefit of habitat quality for the life of the Facility.

E. This Lease facilitates Obsidian's implementation of the WLIP under the HMP and obligates Property Owner to manage and operate the Property (as defined below) consistent with the goals of the WLIP for the life of the Facility as described herein.

NOW THEREFORE, for good and adequate consideration, the parties agree as follows:

1. **Description of Property**. Property Owner grants Obsidian the non-exclusive right to use approximately 1,870 acres of working rangeland in north Lake County, as further described in Exhibit A and shown in Exhibit B ("Property"), for the purposes described herein and subject to the restrictive covenants described herein. Property Owner grants Obsidian a non-exclusive license of ingress and egress to and from the Property over the routes and easements historically and customarily used or hereafter constructed or useful to access the Property. The Agreement excludes oil and gas rights and the improvements consisting of barns, shops, residence, all of which are reserved for the continued use of Property Owner and excluded from the Property. Property Owner is responsible for maintaining all existing improvements on the Property.

2. **Term of Agreement**. The initial term of this Agreement shall be 30 years, commencing on _____ and expiring on _____ ("Initial Term"). Obsidian will have two (individually, an "Option") options to renew this Agreement for five years (individually, a "Renewal Term") at the end of the Term or Renewal Term by providing written notice to Property Owner at least 60 days prior to the then-current expiration of the Term or Renewal Term. The duration of the Initial Term and Renewal Term will be for the life of the Facility's construction and operation.

3. **Rent**. Obsidian agrees to pay Property Owner cash rent in the amount and on the terms set forth in Exhibit C, which shall be redacted in the recorded version of this Agreement. Rent for any partial year shall be prorated based upon the number of days in which this Agreement was effective during such year.

4. **Binding Nature of Agreement**. The terms of this Agreement shall be binding upon the heirs, executors, administrators, successors and assigns of both Property Owner and Obsidian in like manner as upon the original parties. If the Property Owner should sell or otherwise transfer title to the Property, it will do so subject to the terms and conditions of this Agreement. At any time during the Term of this Agreement or any Renewal Term should the Property be transferred, sold or conveyed, be subject to foreclosure, bankruptcy or transferred by any other means whatsoever, the Property Owner, sponsor or administrator shall immediately notify Obsidian in writing.

5. **WLIP Restrictions**. Property Owner covenants and agrees that it will not use the Property in a manner that is likely to undermine the effectiveness or is otherwise contrary to the Obsidian's habitat mitigation and enhancement activities performed on the Property pursuant to the HMP, as may be amended from time to time, set forth in Exhibit D, which shall be redacted in the recorded version of this Agreement.

    a. The following activities are specifically permitted on the Property without violating the terms and conditions of this Agreement: (i) hunting, fishing, hiking, or passive recreation; (ii) fencing to prohibit entrance of livestock and trespassers; (iii) posting of signs; (iv) building or remodeling a primary residence, agricultural building, or similar structure to serve ongoing agricultural operations so long as the total such use does not exceed five (5) acres; (vi) current use of land under existing grazing management plans; and (vii) implementation of approved conservation and wildlife management plans consistent with the HMP.

    b. The following activities are specifically prohibited on the Property under this Agreement: (i) increased grazing above levels approved under existing grazing management plans unless otherwise approved in writing by ODFW; (ii) all nonagricultural uses unless otherwise specified in Section 5(a) above; (iii) grading, mowing, blading, or expansion of impervious surfaces or access road networks; and (iv) divisions of the Property.

c. Activities not specifically permitted or specifically prohibited may be allowed subject to consultation with and prior approval of the Obsidian and ODFW.

~~c.~~d. Property Owner and Obsidian will complete a baseline inventory showing existing development on the Property, identifying any future development area under Section 5(a)(iv), and providing a summary of the existing grazing management plans. The baseline inventory will be included in Exhibit E.

6. **Alterations by Obsidian**. Property Owner acknowledges that the Obsidian intends to use the Property to implement the WLIP and meet its corresponding mitigation obligations described in the HMP. Except as set forth in a written juniper treatment plan or weed control plan developed pursuant to the HMP and provided to Property Owner, Obsidian will make no improvements or alterations on the Property of any kind without first obtaining Property Owner's written consent,. Any alteration will be made in a good and workman-like manner, and in compliance with applicable laws and building codes.

7. **Coordination with Property Owner**. To implement the WLIP, Obsidian will hire one or more contractors (locally, to the extent possible). Obsidian will provide Property Owner written notice of the name and contact information of any contractor engaged by Obsidian to perform work on the Property. Obsidian will provide written notice at least five (5) days prior to the first day of the scheduled work. Such work may include but is not limited to juniper treatment, juniper removal, monitoring, and weed treatment. Property Owner will coordinate with Obsidian if undertaking any activities described in Section 5 above by providing reasonable written notice to ensure that such activities will be performed consistent with the mitigation goals of the HMP. Property Owner also grants limited access rights to ODFW and the Oregon Department of Energy ("ODOE") to access the Property upon prior reasonable written notice to Property Owner and Obsidian for the purposes of inspecting the mitigation work.

8. **Juniper Disposal Methods**. Depending on the local site conditions, the capabilities of the contractor(s), and Property Owner's preferences, cut juniper may be burned onsite, hauled offsite, or some combination of disposal methods may be used. Obsidian will coordinate the selection of the disposal method for cut juniper and slash with Property Owner. If the disposal method is burning, Obsidian or its contractor will obtain all necessary burn permits and coordinate the burn date with Property Owner. To the extent practicable, commercially valuable juniper will be salvaged and hauled offsite and any proceeds will first go to offset rent payments within the last 12 months and then go to the Property Owner.

9. **No Encumbrances or Liens**. Obsidian shall not cause, suffer or permit to be filed against all or any portion of the Property any mechanic's or similar lien for any work done or materials supplied to the Property by or at the request of Obsidian or its authorized agent ("Lien"). If any Lien shall be filed against all or any portion of the Property (i) Obsidian

shall give notice thereof to Property Owner within five business days after the date on which Obsidian first becomes aware of such Lien, and (ii) within 30 days after first becoming aware of such filing and prior to any foreclosure, Obsidian, at its sole cost and expense, shall cause the Lien to be discharged of record or bonded over, failing which Property Owner shall have the right, but shall not be obligated, to discharge the Lien without investigating the validity or amount thereof. Obsidian shall reimburse Property Owner on demand for any amounts so paid or incurred by Property Owner, including reasonable expenses and attorneys' fees. .

10. **Taxes**. Property Owner shall pay when due all real property taxes on the Property and the improvements located on the Property**.**

11. **Insurance by Obsidian**. From and after the Effective Date, Obsidian, at its sole cost and expense, shall obtain and maintain the following insurance during the Term:

    a. Commercial general public liability insurance against any and all claims arising out of liability for personal injury, including illness and death, with limits of not less than $2,000,000 per occurrence, and property damage in and about the Property and otherwise resulting from any acts or operations of Obsidian, with a combined single limit of $2,000,000 per occurrence;

    b. Property insurance coverage Obsidian's personal property protecting against risk of physical loss or damage in an amount not less than the actual replacement cost thereof; and

    c. Workers' compensation and employer's liability insurance as required by applicable law.

    Obsidian is not responsible for paying or maintaining fire and property damage insurance. Any additional insurance coverage for the Property shall be the responsibility of the Property Owner.

12. **Release and Waiver of Subrogation**. The parties hereto release each other, and their respective agents and employees, from any liability for injury to any person or damage to property that is caused by or results from any risk insured against under the insurance policies required to be carried by either of the parties, which policies shall contain a waiver of subrogation by the insurer that provides that the insurer waives all right of recovery by way of subrogation against the other party and its agents and employees in connection with any injury or damage covered by such policy.

13. **Indemnification**. Each party hereby agrees to indemnify, defend and hold harmless the other party and their respective directors, employees and agents from and against any and all third party claims, actions, demands, liabilities, expenses and/or losses, including reasonable legal expenses and reasonable attorneys' fees ("Losses") the extent such Losses result from any, but except to the extent caused by the negligence or misconduct of the other party: (a) breach

of warranty by the indemnifying party contained in this Agreement; (b) breach of this Agreement by the indemnifying party; or (c) negligence or willful misconduct of the indemnifying party or their respective directors, employees, and agents in the performance of this Agreement.

14. **Hazardous Materials.** Neither Obsidian nor any of its employees or contractors (each a "Obsidian Party") shall use, store, deposit, handle, transport, release, or dispose of Hazardous Materials in, on or about the Property in violation of any federal, state or municipal law, decision, statute, rule, ordinance or regulation currently in existence or hereafter enacted or rendered. Obsidian shall indemnify, defend and hold Property Owner harmless from and against any claims, penalties, fines, liabilities, settlements or damages (but excluding consequential damages) arising out of: (1) the release, use, storage, treatment, transportation, transfer, handling or disposal of any Hazardous Materials , on, over, under, from or affecting the Property (a "Release") caused by Obsidian or a Obsidian Party, or (2) any violation of or liability pursuant to environmental laws which is based upon or in any way related to such Release, in each case except (a) those matters to the extent resulting from the negligence or misconduct of Property Owner, its successors and assigns, and their respective directors, officers, employees, contractors and agents, (b) matters that result from Pre-Existing Environmental Conditions unless and only to the extent exacerbated by the gross negligence or willful misconduct of Obsidian or any Obsidian Party, or (c) matters that result from the actions of third parties, including but not limited to the migration of Hazardous Materials to the Property from an offsite source. The indemnity provided in this Section shall survive the termination of this Agreement.

    As used herein, the term "Hazardous Materials" shall mean and be defined as any and all toxic or hazardous substances, chemicals, materials or pollutants, of any kind or nature, which are regulated, governed, restricted or prohibited by any federal, state or local law, decision, statute, rule, or ordinance currently in existence or hereafter enacted or rendered, and shall include (without limitation), all oil, gasoline and petroleum based substances asbestos, toxic molds and per- and polyfluoroalkyl substances ("PFAS"). As used herein, the term "Pre-Existing Environmental Condition" means presence of: (i) Hazardous Materials in soil, groundwater, soil vapor, ambient air or surface water on or about the Property in amounts, concentrations or levels that meet or exceed Environmental Requirements, including cleanup or other standards applicable to Hazardous Materials or which otherwise require remedial action under Environmental Requirements, which first existed or first occurred prior to the Effective Date; or (ii) any other environmental condition which first existed or first occurred prior to the Effective Date. "Environmental Requirements", as used herein, shall mean all applicable federal, state, and local government laws (including common law), rules, regulations, statutes, codes, ordinances, directives, guidance documents, cleanup or other standards, and any other governmental requirements or standards which pertain to, regulate, or impose liability or standards of conduct concerning the use, storage, human exposure to, handling, transportation, release, cleanup, remediation or disposal of Hazardous Materials.

15. **Subordination and Non-Disturbance**. If any mortgage, deed of trust, deed to secure debt or similar instrument encumbers Property Owner's interest in the Property ("Fee Mortgage") and is senior in priority to the Agreement, Property Owner agrees to obtain a nondisturbance agreement in form reasonably satisfactory to Obsidian pursuant to which holder of such Fee Mortgage agrees not to disturb the possession of the Obsidian and its successors and assigns so long as Obsidian and its successors and assigns comply with this Agreement. In the event of foreclosure of any Fee Mortgage by voluntary agreement or otherwise, or the commencement of any judicial action seeking such foreclosure, Obsidian will become the Obsidian of and recognize such lender or purchaser in foreclosure as Obsidian's landlord under this Agreement without change in the provisions of this Agreement. Upon request by such successor in interest, Obsidian will execute and deliver an instrument confirming such attornment, which will recognize this Agreement and the rights of Obsidian set forth herein and shall provide that such successor in interest will not disturb Obsidian in its use of the Property in accordance with this Agreement unless Obsidian fails to comply with this Agreement.

16. **Compliance with Laws**. Obsidian shall comply with all applicable laws concerning Obsidian's specific use, occupancy, and activities in the Property. Property Owner will give prompt notice to Obsidian of any notice it receives of the violation of any law or requirement of any public authority with respect to the Property or the use or occupancy thereof.

17. **Quiet Enjoyment**. Property Owner covenants, represents and warrants to Obsidian that (i) Property Owner is the owner of the Property free and clear of (a) any prior encumbrance inconsistent with Obsidian's rights under this Agreement and (b) any prior mortgage or lien, (ii) Property Owner has the right to lease the Property, (iii) Property Owner shall not cause or allow any activity or use of the Property or Property Owner's adjacent property to interfere with Obsidian's use and enjoyment of the Property or the rights granted to Obsidian under this Agreement, (iv) nothing contained in any easement, covenants, conditions, declarations, limitations, or restrictions now or hereafter of record which are (or shall be) applicable to the Property shall prevent Obsidian from operating in the Property or require Obsidian to make any alterations, repairs modification or installments to the Property or require Obsidian to make any payment or perform any obligations not expressly required by Obsidian under this Agreement, and (v) Obsidian shall be entitled to quiet enjoyment of the Property and to the rights and privileges of Obsidian under this Agreement during the Term.

18. **Notices**. Any notice required or permitted to be given under this Agreement shall be deemed given if delivered personally to an officer or general partner of the party to be notified or sent by (a) United States registered or certified mail, postage prepaid, return receipt requested, or (b) overnight courier service and addressed as follows:

If to Property Owner: _____

_____

_____

If to Obsidian: Obsidian Solar Center, LLC
Attn: David Brown
5 Centerpointe Dr #350
Lake Oswego, OR 97035

With a copy to: Davis Wright Tremaine LLP
Attn: Elaine Albrich
1300 SW Fifth Avenue, Suite 2400
Portland, OR 97201

or such other address as may be designated by either party by written notice to the other. Except as otherwise provided in this Agreement, every notice, demand, request or other communication hereunder shall be deemed to have been given or served upon actual receipt thereof. Accordingly, a notice shall not be effective until actually received. Notwithstanding the foregoing, any notice mailed to the last designated address of any person or party to which a notice may be or is required to be delivered pursuant to this Agreement shall not be deemed ineffective if actual delivery cannot be made due to a change of address of the party or party to which the notice is directed or the failure or refusal of such person or party to accept delivery of the notice.

19. **No Partnership of Joint Venture**. Property Owner shall not, by virtue of this Agreement, in any way or for any purpose, be deemed to be a partner of Obsidian in the conduct of Obsidian's business upon within or from the Property or otherwise, or a joint venturer or a member of a joint enterprise with Obsidian.

20. **Entire Agreement**. This Agreement contains the entire agreement between the parties and, except as otherwise provided herein, can only be changed, modified, amended or terminated by an instrument in writing executed by the parties.

21. **Severability**. If any provision of this Agreement shall be deemed to be invalid, it shall be considered deleted therefrom and shall not invalidate the remaining provisions of this Agreement.

22. **Applicable Law**. This Agreement shall be governed by, and construed in accordance with the laws of the State of Oregon.

23. **Recordation of Memorandum of Agreement**. On the Effective Date, Property Owner will execute, acknowledge, and deliver to Obsidian a memorandum substantially similar to the memorandum attached hereto as Exhibit F~~D~~, documenting the existence of this Agreement.

24. **Counterparts**. This Agreement may be executed in counterparts by the parties hereto and each shall be considered an original, but all such counterparts shall be construed together and constitute one Agreement between the parties hereto.

[signatures on next page]

IN WITNESS WHEREOF, the parties hereunto affixed their signatures the day and year first above written.

Property Owner:	Obsidian:
	OBSIDIAN SOLAR CENTER, LLC
By:_____	By:_____
Name: _____	Name: _____
Its: _____	Its: _____

Exhibit A

Legal Description of Property

Exhibit B

Depiction of Property

Exhibit C

Rent

Exhibit D

Habitat Mitigation Plan

Exhibit E

Baseline Inventory

Exhibit F~~EXHIBIT E~~

Memorandum of Agreement

This document was prepared by and

after recording should be returned to:

Davis Wright Tremaine LLP

1300 SW Fifth Avenue, Suite 2400

Portland, Oregon 97201

Attn: Elaine Albrich

_____

(space above reserved for recorder's use)

Memorandum of Agreement

This Memorandum of Agreement ("Memorandum") is made as of _____, 2__, by and among _____ ("Property Owner"), and **OBSIDIAN SOLAR CENTER, LLC,** an Oregon limited liability company ("Obsidian").

1. **Premises**. Property Owner leases to Obsidian that certain real property located at _____, Oregon and legally described and shown on the attached Exhibit A ("Premises") upon the terms and conditions of that certain Working Lands Improvement Agreement between the parties dated _____, 20__ ("Agreement"), which is incorporated herein by reference.

2. **Term**. The initial term of the Agreement will expire on _____. Obsidian has the option to extend the term for two addition five-year periods, according to the conditions set forth in the Agreement.

3. **Purpose of Memorandum**. This Memorandum is prepared for the purpose of recordation to give notice of the Agreement. This Memorandum shall not constitute an amendment or modification of the Agreement, and in the event of any conflict between the terms of this Memorandum and the Agreement, the terms of the Agreement shall control.

IN WITNESS WHEREOF, the parties hereto have caused this Memorandum to be duly executed as of the Effective Date.

PROPERTY OWNER:

By:_____

Name:

Its:

OBSIDIAN:

OBSIDIAN SOLAR CENTER, LLC,

an Oregon limited liability company

By:_____

Name: _____

Its: _____

STATE OF OREGON)

) ss.

County of _____)

This instrument was acknowledged before me on this ____day of _____, 20__, by _____ in his/her capacity as _____ of Obsidian Solar Center LLC and acknowledged that he/she is authorized on behalf of the company to execute the same.

_____

Notary Public for Oregon

My Commission Expires:_____

STATE OF OREGON)

) ss.

County of _____)

This instrument was acknowledged before me on this ____day of _____, 20__, by _____ in his/her capacity as _____ of _____ and acknowledged that he/she is authorized on behalf of the company to execute the same.

_____

Notary Public for Oregon

My Commission Expires:_____

EXHIBIT A

LEGAL DESCRIPTION OF PREMISES

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TARDAEWETHER Kellen * ODOE

From: Albrich, Elaine <ElaineAlbrich@dwt.com>
Sent: Wednesday, July 22, 2020 11:55 AM
To: TARDAEWETHER Kellen * ODOE
Cc: ESTERSON Sarah * ODOE; WOODS Maxwell * ODOE; Michelle Slater; David Brown; Albrich, Elaine; Bainter, Allison
Subject: Obsidian Solar Center - Supplemental Response to DPO Comments
Attachments: Obsidian_Response to DPO Comments Supplement_07222020 4811-8858-2596 v.1.docx; Attachment 1.pdf; Attachment 2.pdf

Hi Kellen –

Please find attached Applicant's response to DPO comments and testimony from July 20, 2020 (including 6 PDF attachments). I will be sending Attachments 3 through 6 in separate emails due to size.

Thanks for all your work! Elaine

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July 22, 2020

VIA EMAIL

Kellen Tardaewether
Oregon Department of Energy
550 Capitol Street NE
Salem, OR 97301

Re: Response to Comments on the Obsidian Draft Proposed Order – Supplement

Dear Kellen:

On behalf of Obsidian Solar Center LLC ("Applicant"), this letter provides Applicant's response to comments received on July 20, 2020, including comments presented at the public hearing on the Draft Proposed Order ("DPO"), and provides additional evidence to support findings of compliance with the applicable Energy Facility Siting Council ("EFSC") standards. This letter supplements Applicant's earlier submissions (dated May 18, 2020, June 8, 2020, July 16, 2020, and July 20, 2020). Rather than addressing comments by commenter or EFSC standard, we have categorized the comments by topic and responded accordingly.[1]

Dust/Wind Erosion/Agricultural Impacts

Applicant has discussed multiple measures for minimizing dust during construction. As discussed in Mr. Donny Gallagher's testimony (Attachment 1), Swinerton, the selected EPC contractor, developed a proprietary design that allows it to follow native terrain with steel racking to significantly reduce grading. Moreover, Swinerton has developed a method for installing more of the collector system above ground to eliminate miles of DC trenches.

Applicant's proposed dust control measures are consistent with industry standards – thousands of acres of solar pv power generation has been developed in similar conditions, on both public and private land. Applicant proposes the draft Dust Abatement and Management Plan to supplement the BMPs and plans described in the record (Attachment 2). See Attachment 3 for additional information on other examples of dust control plans and a report illustrating that dust and wind erosion are primarily construction related impacts.

[1] For ease of reference, Applicant refers to "the neighbors" generally when summarizing and responding to comments. Applicant recognizes that individual neighbors may have different concerns and not all are represented by Mr. Reeder.

In addition to the measures already contemplated in the DPO, Applicant proposes it is required to conduct pre-construction geotechnical work, and proposes to use information gathered in that phase to further refine its soil protection and erosion control measures.

> *Proposed Condition of Approval*
>
> Prior to construction, certificate holder will place a roadside sign along North Oil Dri Road with the contact information (cell number) for an on-site representative for dust complaints. Certificate holder will also place another sign on the Facility entrance.
>
> *Proposed Condition of Approval*
>
> Prior to construction, certificate holder will finalize the Dust Abatement and Management Control Plan included as Attachment __ to the final order in consultation with ODOE. Certificate holder shall implement plan during construction.

Water/Agricultural Impacts

Applicant intends to purchase and truck water needed during construction from an appropriately licensed supplier. Christmas Valley Domestic Water Supply District ("District") is one of those suppliers. The District does not lack authority to sell water to Applicant as the neighbors allege.

The District is an entity organized under ORS chapter 264 and is treated like a municipality in that the District can use water outside of the place of use specified on its water rights certificates, per ORS 540.510(3). Oregon water law makes clear that the District has the authority to sell water to Applicant. Under the ORS 540.510, the District may apply water to beneficial use on "lands to which the right is not appurtenant" if "the use continues to be for municipal purposes and would not interfere with or impair prior vested water rights." ORS 540.510(3)(a)(B). Applicant's proposed use includes obtaining water from a one or two wells and purchasing water from the District. Use of the wells is exempt under Oregon water law as *de minimis*, meaning such use is considered trivial or insignificant. The water obtained from the District is already accounted for under existing water rights. Accordingly, Applicant's proposed use will not interfere with or impair prior vested water rights, so the question then becomes whether Applicant's proposed use qualifies as a "municipal purpose" in order for the use to take place on lands to which the rights are not appurtenant.

The use contemplated by Applicant clearly falls under the definition of "municipal purpose," which is defined broadly under the OWRD rules. Per OAR 690-300-0010(29), a "municipal water use" includes "all water uses usual and ordinary" to municipal water service systems, including but not limited to commercial and industrial water uses. Applicant contemplates buying water from the District related to three water permits issued to the District for "quasi-municipal use" (permits G-12865, G-12864, and G-11581) which includes ordinary municipal

water use such as commercial and industrial uses. OAR 690-300-0010(40). It follows that Applicant's proposed use – construction of a solar power generation facility – is a quasi-municipal use. For these reasons, the District, as a municipality, has the authority to sell water associated with its three permits for quasi-municipal use to Applicant for use on lands to which the permits are not appurtenant.

In addition, Applicant has preliminarily confirmed with the City of La Pine that if additional or alternative water is needed, Applicant may purchase water from the City of La Pine.

Finally, Applicant proposes up to two on-site groundwater wells. Applicant will limit its water use to the legal volume authorized under state law. If the Facility constitutes a "single commercial purpose," then Applicant will limit its daily usage to 5,000 gallons per day under ORS 537.545(1)(f). This change in water volume does not affect Applicant's ability to implement its dust control measures, because, as outlined above, the majority of Applicant's construction water will come from an appropriately licensed supplier. To the extent necessary, Applicant will put a water meter on any groundwater well located within the Facility boundary to confirm the water usage for the Facility construction and operation.

Applicant's proposed water use does not present a risk to the neighbors' agricultural water supply or create a conflict over inadequate water supply for existing uses, as the neighbors allege.

Noxious Weed Control/Agricultural Impacts

Applicant has developed a Revegetation and Noxious Weed Control Plan ("Reveg/Weed Plan") in consultation with ODFW and Lake County Cooperative Weed Management Area ("LCCWA"). Even Fort Rock/Silver Lake Soil and Water Conservation District supports the weed control methods and treatments described in the Reveg/Weed Plan. LCCWA also provided a comment letter into the DPO record confirming its support for the Reveg/Weed Plan and that it will be working with Applicant to implement the weed control measures during and after construction of the Facility. LCCWA is the area's weed management expert, managing thousands of acres of weed management in partnership with private landowners and local, state and federal agencies.

There are currently no observed noxious weeds on the site. Applicant has been informed by LCCWMA that the risk of adverse weed development is lowest in the first year following soil disturbance and increasing in the succeeding several years. To address that risk, Applicant has consulted with and will work with LCCWMA to monitor the site for noxious weeds, either from Applicant's disturbance activities or fugitive weeds from neighboring properties, and if any are observed will immediately apply treatment to prevent any further spread. Applicant has committed in the Reveg/Weed Plan to ensure that state- or county-listed noxious weeds are absent or constitute only a very small percentage (less than 1 percent) of vegetation. See

Reveg/Weed Plan, Section 4.2. Applicant will do this with regular monitoring (described under Section 4.1) and by continuing to treat weeds in coordination the LCCWA.

Therefore, the record supports Applicant's ability to carry out the Reveg/Weed Plan, and the DPO provides conditions of approval to ensure ongoing compliance. Substantial evidence demonstrates that the spread of noxious weeds would not result in significant adverse impacts to adjacent agricultural uses.

Heat Island/Changes in Dew/Agricultural Impacts

Neighbors have raised concerns about the Facility changing the local environment in a way that would impact agricultural operations. The study provided into the record, *The Photovoltaic Heat Island Effect: Larger Solar Power Plants Increase Local Temperatures*, Greg. A. Barron-Gafford et al (Scientific Reports, Oct. 3, 2016), is actually much narrower than described by the neighbors. The author himself notes that any "pv heat island effect" is constrained to a small area around the pv installation itself.[2] In another report, the author notes that preliminary work on effects of revegetating pv solar farms with grasses results in significant cooling under and around the panels and should greatly reduce any potential heat temperature changes. See Barron-Gafford Research Group, *Response to Technical Queries, Statement of Evidence by Greg Barron-Gafford on Solar Heat Islanding Issues* (May 2018), p 16 (Attachment 4). What the author calls a "heat island effect" actually has been found to result in ambient temperatures and soil moisture levels that are beneficial to growing native grasses. See Elnaz Hassanpour Adeh et al, *Remarkable Agrivoltaic Influence on Soil Moisture, Micrometeorology and Water-Use Efficiency* (Plos One, Nov. 1, 2018) (Attachment 5). Finally, the concept of the "heat island" was discussed during ODOE's solar rulemaking advisory committee ("RAC") meetings and the RAC concluded that the "heat island effect" is a non-issue and did not require further consideration when developing new solar siting standards. Accordingly, ODOE may find that the "heat island" concern would not result in significant adverse impacts to adjacent agricultural uses.

Decommissioning/Financial Assurance

The neighbors have no experience calculating or scoping the decommissioning of a renewable energy facility and provide no evidence for their attacks on the decommissioning estimates presented in the DPO.[3] Applicant's retirement estimates in Exhibit W were developed by Swinerton Renewable Energy, an expert in the field. Further, the retirement estimates were reviewed and revised by ODOE based on its experience with numerous renewable energy projects. The DPO proposes a financial assurance totaling $28.7 million dollars, which Applicant

[2] See https://www.barrongafford.org/photovoltaic-heat-island-effect.html.

[3] In Sections 4 and 5 of Mr. Reeder's letter, he confuses the application of OAR 345-021 versus OAR 345-022, identifying OAR 345-021 as applicable criteria, which the rules are not.

maintains is significantly higher than required to decommission the Facility. Regardless, Recommended Retirement and Financial Assurance Condition 5 ensures that adequate financial assurance be posted for the life of the Facility. Critiques about outdated material in Applicant's application is misplaced – such documents were provided in the preliminary application to demonstrate Applicant's likelihood of obtaining the needed financial assurance and were determined to be adequate by ODOE for completeness. If Applicant is unable to obtain the required financial assurance prior to construction, the Facility cannot be constructed.

See Applicant's April 24, 2020 DPO comments to address other issues raised related to decommissioning and retirement.

Success of Juniper Treatment and Mitigation Ratio

Applicant proposes a 1.2:1 ratio in the Habitat Mitigation Plan to satisfy the EFSC Fish and Wildlife Habitat Standard. Applicant proposes to protect Category 2 from development using the Working Lands Improvement Program ("WLIP") Agreement for the life of the Facility. This action ensures that there is not net loss of habitat quantity or quality and more acreage will be protected under the WLIP Agreement than will be impacted by the Facility. Applicant also proposes to implement the juniper treatment and weed management measures described in the Habitat Mitigation Plan and Reveg/Weed Plan across lands secured by the WLIP Agreement. This action ensures that there is a net benefit of habitat quantity and more habitat will be treated than will be impacted by the Facility. Success of the mitigation is achieved by removing juniper the juniper pursuant to the methods in the Juniper Treatment Plan, which ODFW has found appropriate. Success of the mitigation is also achieved by working with LCCWA to implement the Reveg/Weed Plan, which ODFW also has found appropriate.

Since ODFW's April 24, 2020, Applicant has provided supplemental evidence to demonstrate that a 1.2:1 ratio is adequate to comply with EFSC's Fish and Wildlife Habitat Standard. The mitigation method is proven reliable and successful. See Attachment 6. See also Applicant's May 18, 2020 submittal and Craig Foster's July 20, 2020 DPO Testimony. Applicant proposes monitoring consistent with ODFW's recommendations and anticipates site visits from ODOE and ODFW to inspect the ongoing success of the mitigation. Applicant has revised the WLIP and HMP to incorporate such site visits. The record supports a finding that the likelihood of failure or decline in the mitigation site's habitat value is low. The Theodore Roosevelt Conservation Partnership, the Rocky Mountain Elk Foundation, and the Wetland and Wildlife LLC comments do nothing to undermine the record.

ODFW's continued insistency and lobby for a 2:1 ratio is purely policy driven. If the juniper treatment, the success criteria, the monitoring, and the weed control measures proposed are all appropriate, then there is no basis to continue to argue for a 2:1 ratio. A one-size fits all ratio is not based on science nor is it required by any ODFW or EFSC rule or standard.

<u>Lake County Comprehensive Plan and Zoning Ordinance</u>

The Facility site is zoned A-2 under the Lake County Zoning Ordinance ("LCZO"). The A-2 zone allows the Facility as a conditional use. The Lake County Comprehensive Plan ("LCCP") policies cannot be read in a way that would effectively nullify the LCZO's allowance of energy facilities in A-2 zones. The neighbors try to argue that various LCCP policies prohibit the proposed Facility as a nonagricultural use. If that was the way the LCCP was intended to be read, many other nonagricultural uses allowed outright or conditionally in the A-2 zone would also be precluded (*e.g.*, utility facilities necessary for public service, geothermal exploration and operation, non-farm dwellings, home occupations, hunting preserves and campgrounds, transportation improvements).

As explained in *Walker Associates, Inc. v. Clackamas County*, there is an important assumption that certain agricultural comp plan policies "*necessarily* are violated by a conditional use which puts agricultural land to nonfarm use. If such violations alone require denial of any request for conditional use approval for such nonfarm uses * * * such uses may be approved in the applicable EFU zones is rendered a nullity." 111 Or App 189, 192 (1992) (balancing and weighing when evaluating goal policies is permissible and necessary in county actions on conditional use applications); *Rowan v. Clackamas County*, __ Or LUBA __ (LUBA 89-54, May 9, 1990), *aff'd* 103 Or App 130 (1990). Although the effect on, and consistency of, a proposed use with each goal must be considered, the weight given a particular policy and the magnitude of the effects that a particular use will have on the values that different goals and policies protect will inevitability vary form case to case. *See Walker*, 111 Or App at 194.

<u>Consistency with LCCP Goals and Policies</u>

Applicant properly evaluated the applicable LCCP goals in Exhibit K, using the EFSC land use analysis area to define the scope of the required analysis. The July 20, 2020 letter from Mr. Reeder identified additional LCCP goals and policies that the neighbors argue are also applicable. Applicant addresses these below in order found in the LCCP (not the order presented in Mr. Reeder's letter).

- *LCCP, Goal 1, Policy 2. "That citizens will have an opportunity to participate in all phases of the planning process."*

- *LCCP Goal 1, Policy 3. "That opportunities will be provided for the pubic to respond to preliminary planning documents prior to their finalization."*

- *LCCP Goal 1, Policy 6. "That broad participation in planning activities will be solicited to provide a cross-section of geographical and professional interests."*

Response: The three Goal 1 policies identified by the neighbors all pertain to public involvement and opportunity to provide input into the planning process. There has been tremendous opportunity for public input, with a public comment period running for over three months. There have been public meetings, information sessions, and ODOE and Applicant have readily responded to requests for information. To the extent the neighbors allege error by holding the DPO hearing, reliance on Governor Brown's July 13, 2020 guidance is misplaced. First off, the July 13 guidance does not apply to government meetings, which continue to be regulated by Executive Order 20-16 ("EO 20-16"). Second, EO 20-16 remains in full force and effect and provides ODOE with the legal authority to conduct the July 20 public hearing. Applicant agrees with the opinion expressed by ODOJ Senior Assistant Attorney General Patrick Rowe that Governor Brown's July 13, 2020 guidance on the size of indoor social gatherings does not apply to public hearings conducting by government agencies according to statutory requirements. Governor Brown's July 13 guidance, by its express terms, applies only to indoor social or recreational gatherings in private settings. In the press conference announcing that guidance, Governor Brown made no mention of public meetings or governmental operations of any kind. While that guidance has not yet been reduced to written form, the Governor's press conference on July 13 made the scope of that guidance clear. Additionally, EO 20-16, which permits ODOE to conduct the July 20 hearing and receive testimony that would have ordinarily been provided orally in writing, remains in effect. In EO 20-30, Governor Brown expressed her intention to periodically review the standing executive orders to determine whether they need to be modified or rescinded. *See* EO 20-30 § 2.a. Pursuant to that review, the Governor determined that EO 20-16 "remains in effect, for now." *Id.* at § 2.b(3). As a result, EO 20-16 – which has already been the subject of extensive analysis in these proceedings and expressly provides ODOE with legal authority to conduct the July 20 public hearing – remains in full force and effect. To summarize, nothing contained in Governor Brown's recent Executive Orders or related guidance impacts both the practical and legal basis for proceeding with the scheduled July 20, 2020 public hearing, and the objections raised by the neighbors must be rejected.

- *LCCP Goal 2, Policy 10. "That the area designated on the Land Use Pan map as "Fort Rock Planning Area," will be subject to those policy provisions specifically applicable to Fort Rock."*

- *LCCP Goal 2, Policy 11. "That additional development in Fort Rock be limited to a depth of 600 feet from the existing road system."*

Response: The neighbors attempt to reach these two policies together to require a 600-foot setback for the Facility from public roads. When these two policies are read on their face, and in the context of the LCCP and LCZO, such an attempted interpretation must fail. The land within the planning area is zoned under the LCZO and is not subject and is not subject to an overlay zone or development standards that look to implementing the Fort Rock Planning Area or Policy 11. There is no other reference to Fort Rock Planning Area in the LCZO and no other

policies specifically applicable to Fort Rock except for Fort Rock, the Rural Center in the LCCP. There is no section in either the LCCP or the LCZO addressing what the mapped area is supposed to represent or what planning is supposed to occur within it. In general, comprehensive plan goals and policies are implemented in zoning ordinances in the form of specific use limitations or development standards. Therefore, if there was specific planning undertaken for the Fort Rock Planning Area, it would be embodied in an overlay zone or supplemental provision governing development standards in the planning area to impose the setback requirement. The LCZO contains neither. Therefore, the more appropriate reading of Policy 10 and 11 is to read each as a stand-alone policy. Policy 10 sets a placeholder for future planning for the Fort Rock Planning Area, which was never done. Policy 11, in contrast, applies to Fort Rock, the Rural Center, and is intended to require that new development occur along the frontages of County Roads 5-10 and 5-13. This reading is supported by a plain language reading of Policy 11 – the policy does not reference the "Fort Rock Planning Area" but rather says "***in*** Fort Rock," which is defined in the LCCP on page 130 as being located at the intersection of County Roads 5-10 and 5-13. Further, Policy 11 says that additional development "***be limited to***" a depth of 600 feet from the roads. The language "limited to" implies that the development is supposed to be *within* 600 feet from the road system. This requirement makes sense when planning future development in a rural center – development along the frontages of the rural center is desirable. While not directly implemented in LCZO Article 4, the standards do minimize frontage setbacks and setbacks from county, state and federal highways (see LCZO 4.05). Lake County has never applied Goal 2, Policy 10 and Policy 11 are the neighbors advocate. Accordingly, Applicant maintains that these policies are not applicable to the proposed Facility.

- *LCCP Goal 6, Policy 16 "Land use decision by the County shall avoid creating additional conflicts over inadequate supplies of water from all resources, and shall, wherever possible, ensure the perpetual availability of water resources by protecting the resource from the demands of future uses where necessary."*

Response: Applicant's proposed water use does not present a risk to the neighbors' agricultural water supply or create a conflict over inadequate water supply for existing uses. Applicant proposes to meet its water needs by purchasing water and using on-site exempt groundwater wells. The only new water use not currently accounted for in existing water rights for the area is the well usage limited to 5,000 gallons a day. This type of use is exempt from permit requirements under ORS 537.545(1)(f) as not significant enough to require a permit. Additionally, to the extent necessary, Applicant will install a water meter on any well located within the Facility to ensure the water usage does not exceed applicable limit. Applicant's water needs after construction is complete will be significantly reduced. Accordingly, Applicant's proposed facility will not create any conflict over water supplies or affect the availability of water resources in the area.

- *LCCP Goal 6, Policy 15. "County planning programs shall function in such a manner as to encourage the involvement of county residents in decisions affecting water resources in the area."*

Response: This policy is directed at how Lake County implements the LCCP through the LCZO and is not a policy applicable to individual land use applications. Regardless, to the extent it is applicable, it has been met by the public review process of the application.

- *LCCP Goal 13, Policy 9. "The County supports utilization of renewable energy resources. However, such support is conditioned on a determination that the proposed use can be developed in a timely, orderly, and environmentally sound manner . . ."*

Response: The neighbors do not even make an attempt to specifically address how Applicant's proposal would be inconsistent with this policy, and rather refer back to arguments previously made under other sections of Mr. Reeder's July 20, 2020 letter. It is not even clear what aspect of Policy 9 Mr. Reeder is intending to raise, although it seems to question whether the facility can be developed in an "environmentally sound manner." The record shows that the Facility can be developed in an environmentally sound manner, which is one of the primary purposes of EFSC review.

- *LCCP Goal 13, Policy 13 "Environmental Protection. In all cases the County's support for renewable energy development shall be condition upon satisfactory evidence that sufficient environmental safeguards are provided, Environment concerns of the County shall include, but not be limited to: . . . water consumption . . . "*

- *LCCP Goal 13, Policy 14 "In addition to Policy 13, in all cases the County's support for renewable energy development shall also be conditioned upon a lack of adverse impacts to public facilities or services. In this regard, the County's concerns shall include, but not be limited to: . . . . water supply."*

Response: Comments with regard to Goal 13, Policy 13 and Policy 14 can be addressed together as they both relate again to concerns regarding water supplies and water conservation. The neighbors argue that Applicant designed its facility in a way that consumes water over alternative designs that would conserve water. There is evidence or support, however, for this assertion other than possibly suggesting that waterless solar panel cleaning technology could be employed. Graveling, paving, or planting a monocrop within the site boundary does not amount to a viable design alternative. With regard to concerns related to water supply, Applicant has already explained and shown that its proposed water use would not affect water supplies in the area. Applicant proposes to obtain water from a combination of de minimis groundwater resources and purchase of an appropriately licensed supplier. The only water use added to the area could be from the exempt groundwater wells, which are limited by state law. Applicant has

analyzed the Facility's anticipated water needs in Exhibit O and will not require any additional water rights, thus ODOE may find that there will be very little to no impact on existing water resources. Accordingly, Applicant's proposed use is consistent with Goal 13, Policies 13 and 14.

Compliance with LCZO 24.19

LCZO 24.19 provides general conditional use criteria for all nonfarm uses in the A-2 zone. It is intended to implement ORS 215.296 and ensure that the policies for agricultural protection are not undermined. Applicant reviewed its analysis of LCZO 24.19 in Exhibit K. Applicant analyzed LCZO 24.19(A) and (B) using the neighboring farm uses within the Exhibit K land use analysis area. Applicant analyzed LCZO 24.19(C) by looking at a larger area because the standard requires a look behind "adjacent" or "surrounding" lands. This reading is consistent with prior Lake County reviews. The neighbors generalize and mischaracterize Applicant's Exhibit K analysis. They also attempt to argue that the Facility does not meet LCZO 24.19(A) because the Facility is not consistent with the intent and purpose of the policies in ORS 215.243. This argument is hinged on characterizing the Facility as "urban development," which it is not. A solar pv power generation facility is not "urban development" – it is a use expressly authorized on agricultural land by the Oregon legislature and regulated as a conditional use by local and state siting standards. The neighbors' reliance on ORS 215.243(3) is misplaced. Applicant did not ignore this provision, it is not applicable.

Goal 3 Exception

The neighbors raised several legal arguments objecting to the DPO findings for the Goal 3 exception. None rise to the level of warranting reconsideration of the DPO findings or the proposed conditions. The neighbors' arguments appear, in large part, to rely on general use classification statements in the LCCP rather than on specific goals or policies from the LCCP. These general statements are not applicable criteria as alleged nor does the language amount to applicable LCCP policies within the meaning of LCZO 24.01(A)(1). Therefore, these arguments are disregarded. The neighbors also attempt to argue a conflict of laws triggering the balancing test in OAR 345-022-0000(1)(b). The first line of subpart (1)(b), however, says "[e]xcept as provided in OAR 345-022-0030 for land use compliance * * *," clearly indicating that the provisions of subpart (1)(b) do not apply as the neighbors intend. Moreover, there is no conflict of law that would require EFSC to resolve the conflict "consistent with public interest." EFSC was granted authority by the Oregon legislature to apply a different review standard when considering goal exceptions for facilities under ORS 469.504. This is intentional and a recognition of state's interest in promoting its energy policies. See ORS 469.010, 469.310.

Other factual arguments are raised in objection to the Facility's Goal 3 exception but none support denial of Applicant's Goal 3 exception. Many of the neighbors' arguments are already addressed by Applicant's response above or evidence in the record. The Facility site has low quality, low producing soils; there are no water rights and no ability to access irrigation rights;

and the acreage cannot support a commercial ranching operation (*see, e.g.*, Mr. Morehouse's letter). Potential impacts have been identified and mitigated, as discussed above. The project will have significant direct and indirect economic benefits for the area, including increased property tax revenue for the life of the Facility. The record provides substantial evidence supporting the Goal 3 exception and neighbors' arguments do not warrant reconsideration of the DPO findings or additional conditions of approval.

Conclusion

Applicant has been aware of the neighbors' concerns over potential agricultural impacts since the beginning of the project permitting and has worked diligently to ensure that it can design, construct, and operate the Facility without causing significant adverse impacts to neighboring properties. The DPO contains numerous conditions of approval that require implementation of construction plans, BMPs, and ongoing monitoring to ensure that such impacts to not occur. In addition, Applicant proposes additional conditions in response to concerns it heard from the DPO hearing and testimony.

Thank you for your consideration.

Davis Wright Tremaine LLP

Elaine R. Albrich

Enclosures

cc: David W. Brown
Michelle Slater

Donny's Testimony

Intro:

- Donny Gallagher
- Director of Engineering, Swinerton
    - Been with Swinerton's renewable energy group since 2013 (7 years)
    - Before that I spent 8 years as a civil engineering consultant primarily in the land development market
    - While at Swinerton, I have overseen the design and permitting of over 150 turnkey Engineering, Procurement, and Construction (EPC) utility scale solar projects totaling more than 5GW.
        - 22 Projects in Southeast Oregon totaling over 200MW
            - 8 projects in the North Great Basin area (~90MW)
    - As Swinerton has been selected as the EPC contractor for the Obsidian Solar Center, I will be overseeing the design of the Obsidian Solar Center project
- Swinerton's background
    - 130 year old company (Swinerton was founded in 1888)
    - Renewable Energy Division founded in 2008
    - 100% Employee owned company - as employ-owners, every individual is accountable to completing projects to the highest quality.
    - Over 5 GW of installed projects. Racked #2 EPC in the U.S. by Solar Power World in 2019.
        - 22 Projects in Southeast Oregon totaling over 200MW
            - 8 projects in the North Great Basin area (~90MW)
                - Bear Creek Solar (10 MW), Deschutes County, 2017
                - Lakeview Solar (10MW), Lake County, 2017
                - Lakeview 500 (0.5MW), Lake County, 2013
                - Lakeview Airport (47MW), Lake County, 2019
                - Garrett Solar (10MW), Lake County, 2019
                - Black Cap 1 (2MW), Lake County, 2012
                - Black Cap 2 (8MW), Lake County, 2016
    - Swinerton's Operations & Maintenance arm, SOLV, was recently named #1 O&M provided for the fourth year in a row by Wood MacKenzie. SOLV oversees 6.5 GW (6,500 MW) of solar across 26 states.

Today I'm hoping that I can address some of the concerns that have been raised, specifically around dust and traffic safety.

Regarding dust control, there are a lot of mitigation measures that we implement to improve our ability to manage dust:

- First off, we manage dust through intelligent design
    - Swinerton has developed a proprietary design that allows us to follow the native terrain with the steal racking structure that supports the solar panels and greatly reduces the grading necessary.
    - Swinerton has also developed an above ground DC collection system that will eliminate miles of DC trenches.
    - Swinerton also minimizes roads to only what is needed for fire safety (i.e. access to inverters) and does not build temporary construction roads.

    - Rather than using the traditional construction technic of clearing and grubbing, we use mowing/brush beating to keep the root structure intact.
- Rolling construction:
    - The site will be constructed like a moving assembly line:
        - Civil site work (mowing, roads, minor grading if needed)
        - Pile foundations
        - Racking
        - Electrical
        - Module install
        - Commissioning
    - This approach ensures that we will not be disturbing thousands of acres at a time.
- Even with the reduction in ground disturbance and preservation of existing root structures, there is going to be dust. For that, we implement an erosion control / dust control plan.
    - Swinerton's philosophy is that the erosion control plan / dust control plan are living documents. These plans discuss the goal - minimize erosion (including dust which is wind erosion). These plans provide suggested Best Management Practices (BMPs) to accomplish this goal. If the intent is not being met with one BMP, then the plan allows for other BMPs to be utilized until the intent of the plan (goal) is met. Sample BMPs:
        - Crimped straw
        - Straw mulch
        - Hydromulch
        - Water
    - Water is the most common BMP to keep dust down. We will run water trucks all day along our access roads to keep dust down.
- If for some reason none of those dust control measures work, we provide a way for the public to contact the site directly. There will be a large sign on the fence to the facility with the cell phone number to our on-site dust control person. If anyone sees any issues, they can call this person directly and voice their concern.

Regarding Traffic:

- We understand that traffic route and road conditions are a concern to the community. The project team has been in conversations with the County Road Master and will be entering into a Road Use Agreement that requires the project to repair any damage to the roads at the project's costs.
    - Based on our conversations with the Road Master, the project has agreed to use the Road Master's preferred main access route (which is from the North via Oil Dry Road).
    - We will be utilizing water as our primary means of dust control along this route and will also have a sign with the dust complaint phone number that I mentioned earlier posted along the route so that the public can notify us if we are not doing an adequate job maintaining the dust.
- We also understand that traffic safety is a concern. Swinerton takes all safety matters very seriously. Our moto is YFNY (You're Family Needs You).
    - Our standard approach to follow the American National Standards Institute, Manual of Uniform Traffic Control Devices for Streets and Highways or the local AHJ (in this case County) guidelines for traffic control measures (i.e. appropriate signage and speed reductions), whichever offers the greatest degree of safety. Following these industry standards for construction traffic safety have proven successful time and time again. Swinerton has experienced very few traffic related safety incidents over the years.

I also wanted to recognized the issues the Fort Rock/Silver Lake Soil and Water Conservation District brought up in their comments. Their comments are focused on wind erosion, having the right revegetation seed mix, timing of revegetation efforts following temporary disturbance and construction activities, soil compaction, and noxious weeds.

- Wind erosion (dust control) was addressed earlier
- Revegetation seed mix will be largely addressed by my colleague, Jen Kirby
- Soil Compaction:
    - Our strategies for reduced ground disturbance (including mowing rather than grubbing, reducing grading with a terrain following racking system, reducing trenching with above ground DC collection) will help preserve the native compaction levels.
    - Our rolling construction approach also prevents repetition of construction activities in the same area and therefore reduces the likelihood of increased compaction.
    - We also use primarily rubber-tire / rubber-tracked equipment.

Lastly, I wanted to take a second to correct a typo in the project description that states we would have millions of miles of cable. That is incorrect. Depending on the exact solar panel brand that is selected we will have between 3,000 and 6,000 miles of cable.

Thank you very much; that concludes my testimony.

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Obsidian Solar Center

Fugitive Dust Abatement and Management Plan (Draft)

The objective of the fugitive Dust Abatement and Management Plan (the "DAMP") is to detail the range of practices and tools designed to address potential impacts from construction and operation of Obsidian Solar Project (the "Facility"). The DAMP provides guidance to construction and field personnel on measures intended to minimize effects during construction activities and adapt management and abatement techniques in real-time from the field to respond to the dynamic environment. It will be the responsibility of the Facility and its contractors, working with designated environmental monitors, to comply with measures identified in this document and to be responsive to current and changing conditions on and around the development site.

The DAMP is intended to supplement and support the Facility's Erosion and Sediment Control Plan, which will be included in the National Pollution Discharge Elimination System (NPDES) 1200-C Construction Stormwater Permit, together with the required erosion and sediment control best management practices (BMPs).

Dust Control Coordinator

There Facility's construction contractor shall be the designated fugitive dust control coordinator and shall manage implementation of the DAMP for the Facility and be responsible for implementing the fugitive dust control measures specific in the DAMP during construction. The dust control coordinator shall also:

- Have the DAMP available at the construction site at all times during Facility construction and operation;
- Implement the DAMP and ensure that all employees, workers and subcontractors know their responsibilities regarding dust control;
- Monitor construction activity to ensure compliance with the DAMP;
- Promptly log and respond to reports on the DAMP hotline;
- Identify when reasonably available control measures are not adequate and when standby control measures (e.g., increased watering) shall be implemented.

Fugitive Dust Sources and Reasonable Available Control Measures

Fugitive Dust Source	RACM(s)
General	Contractor will maintain the natural topography and vegetation of the site to the extent possible, including by limited grading and limited establishment of temporary access roads.
	Contractor will turn off equipment when it is not in use.
	Mowing and rolling techniques will be used wherever possible to maintain plant root systems for soil stabilization.

Fugitive Dust Source	RACM(s)
Driving inside the Site	The primary vehicular access roads/driveways within the project site will be stabilized with water for the duration of construction sufficient to eliminate visible and sustained dust from vehicular travel and wind erosion.
	Unless other limitations apply, traffic speeds within the site will be limited to 15 miles per hour with the exception that vehicles may travel up to 25 miles per hour on stabilized unpaved roads within the site as long as such speeds do not create significant visible dust emissions. Traffic speed signs shall be displayed prominently at all site entrances and exits.
Deliveries and Construction Traffic	Unless other limitations apply, construction equipment and vehicles containing construction deliveries will limit their speed on gravel access roads to 25 miles per hour.
	Contractor shall install a minimum of two Dust Control Hotline signs similar to the sample attached as Exhibit A, one on Oil Dri Road and one on the primary access route to the Facility, providing direct access to the dust control coordinator.
	The speed limit for construction vehicles preparing or installing the transmission line between the main project site and the step-up substation site shall be limited to 15 miles per hour except that speeds will be reduced to no more than 10 miles per hour within 200 feet of a residence
	All dirt or gravel vehicular access road(s) used as primary access routes for deliveries of parts, equipment, or personnel to the project site shall be stabilized with water for the duration of construction sufficient to eliminate significant and sustained visible dust from vehicular travel and wind erosion.
	When wind speeds exceed _ miles per hour[1], construction contractors will minimize new disturbances to the extent possible and/or mobilize additional water trucks to minimize fugitive dust from exposed surfaces.

[1] This figure will be determined prior to construction following an analysis of available historic wind speed data from the Bureau of Reclamation AgriMet (Cooperative Agricultural Waethe Network) for the Christmas Valley, Oregon weather station; https://www.usbr.gov/pn/agrimet/webaghrread.html

Fugitive Dust Source	RACM(s)
Earth Moving Activities	When feasible, use a water truck to maintain moist disturbed surfaces and actively spread water during visible dusting episodes to minimize significant visible dust emissions.
	Minimize disturbance areas to the maximum extent feasible.
	For non-road or parking area earthen surfaces, stabilize surfaces by gravel, chemical or other means to prohibit significant and sustained visible fugitive dust from wind erosion.
Removing and Hauling Sand, Soil or other Loss Materials	Soil load shall be kept below 6 inches of the freeboard of the truck
	Drop heights shall be minimized when loaders dump soil into trucks.
	Gate seals should be tight on dump trucks.
	Haul trucks will be covered with a tarp or other suitable cover.

Standby Control Measures

If, after implementation of the RACMs dust emissions have not been reduced to acceptable levels, standby measures will be immediately implemented. Standby control measures may include additional watering of disturbed areas or soil piles, application or additional applications of soil stabilizers, covering excavated soil piles, temporarily reducing the permitted speed limits, or temporarily suspending the source of the dust emission until wind speed is reduced.

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Exhibit A

Dust Control Hotline

Dust Control Plan Approval Requirements

Mojave Desert Air Quality Management District

A Dust Control Plan (DCP) may be required by the Mojave Desert Air Quality Management District (District), [1] by District Rule 403.2, by permit condition, or as a mitigation measure. The District will not approve a DCP unless it complies with this document. Submission of a DCP for District approval may incur a review and inspection cost as specified in District Regulation III. District approval of a DCP makes it an enforceable document by the District and failure to comply with the approved elements of a DCP renders the owner/operator and their contractors liable to enforcement action by the District.

DCP Format

Include a cover letter on letterhead which declares responsibility for the affected site. Include a statement of purpose and commitment, and have a signature from the project owner. Include name, mailing address, phone numbers and emails for all project contacts including: project owner, general contractor, dust control preparer and 24-Hour point of contact. The 24-hour point of contact must be available 24/7 and have authority to commit additional assets to control dust after hours, weekends and holidays. The DCP may be submitted by mail or in person to the District (14306 Park Avenue, Victorville, California 92392) or electronically to reporting@mdaqmd.ca.gov (as an attachment in portable document format (pdf)).

The following are mandatory elements of a DCP:

Affected Facility, Activity or Location Description

As an umbrella document, the DCP should describe reasonably foreseeable or planned, as well as existing, activities on the described site (this will also reduce the need for revisions). An umbrella DCP can be used for all applicable operations at a given site and can be the reference for mitigation measures for each applicable operation or project at the site.

A - General Location (City, APN # and major cross streets. Include the land use agency with jurisdiction over the project.

B - Specific Location (plot plan, site plan, facility layout, etc.). A map or layout (hand-drawn if necessary) is mandatory. Indicate preferred access to the site, as well as major site features such as storage piles, equipment locations, and road locations (paved, gravel and earthern).

C - Type of Features. Identify disturbed areas and potentially disturbed areas, include actual or estimated disturbed surface area as well as the expected method of disturbance (vehicle travel, blasting, handling, tilling, cut and fill, etc.). Additionally, report surface area for all disturbed areas that will be left inactive for more than seven days.

D – Equipment List and Activities. Identify equipment (in list form) and activity each piece of equipment is performing. Include all equipment that will be producing dust

[1] The District requires Dust Control Plans for all solar development projects of at least one megawatt installed capacity or one acre in size.

(heavy earthmoving and hauling equipment, fuel burning equipment, vehicles by type, material handling equipment, etc.). Indicate if any structural demolition is planned.

E – Dust Control Measures. Identify the number of water trucks available on-site as well as the location and size of the water source. List any dust suppressant products that will be used, application frequency and rate. Provide any "other dust control measures" that will be used, ie. wind fencing (with less than 50% porosity), gravel, pavement, berms etc. Specify "treatment to prevent track out" ie. gravel pad, wheel wash, grizzly.

F – Dates. Provide start and end date for any dust generating activities and soil disturbance activities.

Mandatory Actions List

A - Required Signage. Signage shall be erected prior to the commencement of construction. A minimum 48 inch high by 96 inch wide sign containing the following shall be located within 50 feet of each project site entrance, meeting the specified minimum text height, black text on white background, on one inch A/C laminated plywood board, with the lower edge between six and seven feet above grade, with the contact name and contact information for the 24-hour point of contact. If the contact changes the sign must be updated with the new contact information within 30 days.
"[Site Name] {four inch text}
[Project Name/Project Number] {four inch text}
IF YOU SEE DUST COMING FROM {four inch text}
THIS PROJECT CALL: {four inch text}
[Contact Name], PHONE NUMBER (XXX)-XXX-XXXX {six inch text}
FOR AFTER-HOURS CALL: {four inch text}
[24-Hour Contact Name], PHONE NUMBER (XXX)-XXX-XXXX {six inch text}
If you do not receive a response, Please Call {three inch text}
The MDAQMD at 1-800-635-4617 {three inch text}"

B - (during construction phase) Operator shall use a water truck to maintain moist disturbed surfaces prior to disturbance and immediately after disturbance, and shall actively spread water during visible dusting episodes (such as high wind conditions) to minimize visible fugitive dust emissions.

C - For projects with exposed sand or fines deposits (and for projects that expose such soils through earthmoving), chemical stabilization or covering with a stabilizing layer of gravel will be used to eliminate visible emissions from sand/fines deposits.

D - Wind fencing or the equivalent will be installed to a minimum of four feet of height on the entire perimeter of the project. The wind fencing will be maintained as needed to keep it intact and remove windblown dropout.

E - All maintenance and access vehicular roads and parking areas shall be stabilized with chemical, gravel or asphaltic pavement sufficient to eliminate visible fugitive dust from vehicular travel and wind erosion. All other earthen surfaces within the project area shall be stabilized by natural or irrigated vegetation, compaction, chemical or other means sufficient to prohibit visible fugitive dust from wind erosion.

F - The operator will ensure that loaded vehicles will not exceed 15 miles per hour on public and private earthen or gravel roads. This limit will be posted on permanent private roads.

G - The operator will ensure that bulk material carried on haul trucks operating on paved roads will be properly covered so as not to fall on to the paved surface.
H - The operator will promptly remove (flush or sweep) any visible material tracked from the project onto adjoining public paved roads. Promptly is defined as not later than 24 hours.
I - (for a construction project) The operator will follow a construction schedule that specifies the construction of parking lots and paved roads first, and upwind structures prior to downwind structures.
J - Operator will maintain the natural topography to the extent possible during grading and other earth movement.
K - Operator will stabilize storage piles and disturbed surfaces which are idle for two weeks or more. Stabilization shall be sufficient to prevent wind erosion.
L – Appointed operator, identified by the contractor, will stop all work and focus on dust control during high wind event. Outdoor construction activities that disturb the soil will cease whenever visible dust emissions cannot be effectively controlled.
N – Prior to the start of earth moving or site-clearing activity, Contractor must meet with District Field Inspector on-site to review DCP requirements. Inspector will confirm compliance.

Elective Actions List
List other actions that will be performed to reduce dust emissions.

District Approval Process
The District will review any submitted Dust Control Plan (DCP) for completeness and adequacy in comparison with this guidance. The District will provide written notification of approval or disapproval, with a carbon copy to the Lead Agency for the project (if known). An approved DCP is an enforceable public document.

If a significant change occurs to the facility or operations covered by the DCP, please notify the District and submit an appropriately modified DCP within 60 days of the change.

Appendix O

Dust Control Protocol

APPENDIX O
DUST CONTROL PROTOCOL FOR THE PALEN SOLAR PV PROJECT

Prepared For: **Bureau of Land Management**
Palm Springs – South Coast Field Office, CA

Prepared By: **EDF Renewable Energy**
505 14th Street, Suite 1150
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Date: February 2017

SUMMARY

The objective of the Dust Control Protocol is to detail practices designed to address potential impacts from construction of the Palen Solar PV Project (Project). This Protocol has been developed as part of the Plan of Development (POD). This Protocol provides guidance to construction and field personnel on measures identified to minimize effects during construction activities associated with the Project. It will be the responsibility of Palen Solar PV Project and its contractors, working with designated environmental monitors, to comply with measures identified in this document

The Dust Control Protocol has been developed to reduce fugitive dust emissions during construction of the Palen Solar PV Project. This Protocol:

- Identifies sources of fugitive dust that are anticipated to occur during construction of the Project;
- Defines the roles and responsibilities of the people that are responsible for implementing the Protocol.
- Identifies Reasonably Available Control Measures (RACMs) that shall be implemented during construction of the Project to reduce fugitive dust emissions; and
- Identifies standby control measures that shall be implemented if the RACMs are not adequately controlling fugitive dust.

PROJECT LOCATION

The Palen Solar PV Project would be located in Riverside County, 10 miles east of Desert Center on lands administered by the BLM, Palm Springs-South Coast Field Office. The project site is within the Riverside East Solar Energy Zone (SEZ) of the BLM's Western Solar Plan. The Project's ROW application covers approximately 4,200 acres of federal public lands administered by the BLM. An application has been filed for a ROW grant to construct, operate, maintain and decommission the project and a double circuit 230 kV overhead transmission line (gen-tie) on the BLM-administered land. If the ROW grant is approved, the final POD and all appendices will be attached to the Decision Record.

PROJECT OVERVIEW

The project would construct and operate a 500 megawatt (MW) nominal capacity, alternating current (AC) solar PV energy-generating project that would be expected to produce approximately 1,599,000 megawatt-hours per year[1] (MWh/y). The proposed solar facility would consist of several main components:

- A single large solar field with two smaller adjacent solar fields for a total of 3 solar fields;
- Two-hundred power blocks of electrical generating capacity of 2.5 MW each;
- An electrical substation;
- An operations and maintenance building;
- Up to 10 on-site groundwater wells;
- One temporary 28-acre construction laydown area;
- A roadway system consisting of internal and perimeter roads;
- An access road along the generation tie-line;
- A main access road from the I-10/Corn Springs interchange; and
- A double circuit 230 kV gen-tie extending from the project substation yard to the existing SCE Red Bluff Substation.

[1] The number of megawatt-hours per year is a measure of the system's energy, which is the amount of power generated by the system during a year.

DUST CONTROL

The objective of the Dust Control Protocol is to identify potential dust emission sources and provide guidance to construction and field personnel on measures to control the generation of fugitive dust during construction activities. Fugitive dust could be generated directly from construction of the solar PV project, ancillary facilities and associated traffic. The following construction related activities have been identified as having the potential for generating fugitive dust:

- Vehicle and motorized equipment movement on unpaved access roads;
- Clearing and grading;
- Topsoil removal;
- Cutting, filling, and backfilling;
- Bulk material loading, hauling, and unloading;
- Use of material storage piles; and
- Use of parking, staging, and storage areas.

It is the responsibility of the project contractor(s) and the designated environmental monitor to ensure all sources of dust generation are identified and fugitive dust and other pollutant emissions are minimized.

ROLES AND RESPONSIBILITIES

The Palen Solar PV Project is subject to PSPP mitigation measures AQ-SC-1 (Air Quality Construction Mitigation Manager), AQ-SC-2 (Air Quality Construction Mitigation Plan), AQ-SC-3 (Construction Fugitive Dust Control), AQ-SC-4 (Dust Plume Response Requirement), AQ-SC-5 (Diesel Fueled Engine Control), AQ-SC-6 (Emission Standards Vehicles), AQ-SC-7 (Operation Dust Control Plan), and AQ-SC-8 (Copies of Documents). The Project is also subject to South Coast Air Quality Management District's (SCAQMD) Rule 403. It will be the responsibility of Palen Solar PV Project and its contractors, to obtain all necessary permits from the District. Per the mitigation measures, a separate air quality construction mitigation plan will be submitted prior to the issuance of the Authority-to-Construct (ATC) documents for the facility from SCAQMD. The final mitigation plan will include and implement the specific requirements of the mitigation measures listed above, particularly AQ-SC-3.

The following describes the roles and responsibilities of key parties to be involved in all aspects of the Protocol. The project construction contractor shall be the designated fugitive dust control coordinator and shall manage implementation of the Protocol for Palen Solar PV Project and be responsible for implementing the fugitive dust control measures specified in the Protocol during construction of the Project. The dust control coordinator shall also:

- Have the Protocol available at the construction site at all times during Project construction and operation;
- Implement the Protocol and ensure that all employees, workers, and subcontractors know their responsibilities regarding dust control;
- Monitor construction activity to ensure compliance with the Protocol;
- Report incidents; and
- Identify when reasonably available control measures are not adequate and when standby control measures (e.g., increased watering) shall be implemented.

The project contractor shall use environmental monitors to monitor compliance with the Protocol. The environmental monitors shall be responsible for recording and reporting any incidents related to dust control.

FUGITIVE DUST SOURCES & REASONABLY AVAILABLE CONTROL MEASURES

Table 1 identifies all sources of fugitive dust emissions associated with the Project and, for each source identified, provides at least one Reasonably Available Control Measure (RACM). These potential RACMs can be utilized or installed throughout the construction of the Project.

Fugitive dust will be controlled during construction by reducing vehicle and equipment speeds on unpaved surfaces, minimizing the amount of new exposed soil /surface disturbance, and periodic application of clean water as directed by the environmental monitors to exposed disturbed surface areas (application of water will be via water trucks). The environmental monitor and dust control coordinator will monitor construction to ensure that dust does not leave the work area and accumulate on adjacent dwellings or roadways. If visible dust dispersion to off-site locations becomes apparent, the environmental monitor will establish a maximum speed limit in dust-prone areas, cover stockpiles, and/or apply additional water to access roads and work areas as necessary (see Table 1).

TABLE 1: FUGITIVE DUST SOURCES AND REASONABLE AVAILABLE CONTROL MEASURES

Fugitive Dust Sources	RACM(s)
General	The operator will maintain the natural topography to the extent possible.
	The operator will follow a construction schedule that specifies the construction of parking lots, laydown areas and paved roads first whenever feasible.
	The contractor will turn off equipment when it is not in use.
	Where feasible, mowing and rolling techniques will be used to maintain plant root systems for soil stabilization.
Use of roads and parking areas	The main vehicular access roads to the project site shall be stabilized with chemical or gravel sufficient to eliminate visible fugitive dust from vehicular travel and wind erosion.
	Unless other limitations apply, traffic speeds on unpaved roads shall be limited to 10 miles per hour with the exception that vehicles may travel up to 25 miles per hour on stabilized unpaved roads as long as such speeds do not create visible dust emissions. Traffic speed signs shall be displayed prominently at all site entrances and at egress point(s) from temporary staging and parking areas.
Earth moving activities	When wind speeds exceed 20 miles per hour (mph), construction contractors will minimize new disturbance to the extent possible and/or mobilize additional water trucks to minimize fugitive dust from exposed surfaces.
	Graded site surfaces shall be stabilized upon completion of grading when subsequent development is delayed or expected to be delayed more than thirty days, except when such a delay is due to precipitation that dampens the disturbed surface sufficiently to eliminate visible fugitive dust emissions.

Fugitive Dust Sources	RACM(s)
Disturbed surface area	When feasible, use a water truck to maintain moist disturbed surfaces and actively spread water during visible dusting episodes to minimize visible fugitive dust emissions.
	Minimize disturbance areas to the maximum extent feasible.
	For non-road or parking area earthen surfaces, stabilize surfaces by compaction, chemical or other means sufficient to prohibit visible fugitive dust from wind erosion.
Removing and hauling soil, sand, and other loss materials	Soil loads shall be kept below 12 inches of the freeboard of the truck.
	Drop heights shall be minimized when loaders dump soil into trucks.
	Gate seals should be tight on dump trucks.
Other unanticipated sources	Other fugitive dust control measures as necessary to comply with South Coast Air Quality Management District (SCAQMD) Rules and Regulations may be implemented.

STANDBY CONTROL MEASURES

If, after implementation of the RACMs dust emissions have not been reduced to acceptable levels, standby control measures will be immediately implemented. Standby control measures may include additional watering of disturbed areas or soil piles, application or additional applications of soil stabilizers, covering excavated soil piles, temporarily reducing the permitted speed limits, or temporarily suspending the source of the dust emissions until wind speed is reduced.

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The impact of photovoltaic (PV) installations on downwind particulate matter concentrations: Results from field observations at a 550-MW_{AC} utility-scale PV plant

Dwarakanath Ravikumar & Parikhit Sinha

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TECHNICAL PAPER

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The impact of photovoltaic (PV) installations on downwind particulate matter concentrations: Results from field observations at a 550-MW_{AC} utility-scale PV plant

Dwarakanath Ravikumar[a] and Parikhit Sinha[b]

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ABSTRACT

With utility-scale photovoltaic (PV) projects increasingly developed in dry and dust-prone geographies with high solar insolation, there is a critical need to analyze the impacts of PV installations on the resulting particulate matter (PM) concentrations, which have environmental and health impacts. This study is the first to quantify the impact of a utility-scale PV plant on PM concentrations downwind of the project site. Background, construction, and post-construction $PM_{2.5}$ and PM_{10} (PM with aerodynamic diameters <2.5 and <10 µm, respectively) concentration data were collected from four beta attenuation monitor (BAM) stations over 3 yr. Based on these data, the authors evaluate the hypothesis that PM emissions from land occupied by a utility-scale PV installation are reduced after project construction through a wind-shielding effect. The results show that the (1) confidence intervals of the mean PM concentrations during construction overlap with or are lower than background concentrations for three of the four BAM stations; and (2) post-construction $PM_{2.5}$ and PM_{10} concentrations downwind of the PV installation are significantly lower than the background concentrations at three of the four BAM stations. At the fourth BAM station, downwind post-construction $PM_{2.5}$ and PM_{10} concentrations increased marginally by 5.7% and 2.6% of the 24-hr ambient air quality standards defined by the U.S. Environmental Protection Agency, respectively, when compared with background concentrations, with the $PM_{2.5}$ increase being statistically insignificant. This increase may be due to vehicular emissions from an access road near the southwest corner of the site or a drainage berm near the south station. The findings demonstrate the overall environmental benefit of downwind PM emission abatement from a utility-scale PV installation in desert conditions due to wind shielding. With PM emission reductions observed within 10 months of completion of construction, post-construction monitoring of downwind PM levels may be reduced to a 1-yr period for other projects with similar soil and weather conditions.

Implications: This study is the first to analyze impact of a utility photovoltaic (PV) project on downwind particulate matter (PM) concentration in desert conditions. The PM data were collected at four beta attenuation monitor stations over a 3-yr period. The post-construction PM concentrations are lower than background concentrations at three of four stations, therefore supporting the hypothesis of post-construction wind shielding from PV installations. With PM emission reductions observed within 10 months of completion of construction, postconstruction monitoring of downwind PM levels may be reduced to a 1-yr period for other PV projects with similar soil and weather conditions.

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Introduction

Photovoltaic (PV) deployments are increasing worldwide to meet climate goals, reduce the reliance on electricity derived from fossil fuels, and avoid the associated global warming impacts (Fthenakis and Kim, 2011; U.S. Department of Energy, 2012; Ravikumar, 2013, 2016; International Energy Agency, 2014; Ravikumar et al., 2014, 2017). Annual utility-scale PV installations (>1 MW_p capacity) in the USA have grown from 310 to 3950 MW_p from 2010 to 2014 (Solar Energy Industries Association, 2015), as they are economically favorable when compared with other models of PV deployments (Goodrich et al., 2012). Although outperforming conventional fossil-fuel electricity sources in multiple impact categories (Fthenakis et al., 2008; (Fthenakis and Kim,

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2010; Desideri et al., 2012; National Renewable Energy Laboratory [NREL], 2012), the environmental performance of large-scale utility-scale PV plants requires environmentally responsible land management and installation practices to increase land use efficiencies (Hernandez et al., 2014), reduce potential wildlife impacts (Lovich and Ennen, 2011), minimize impacts on local flora (Pocewicz et al., 2011; Guerin, 2017), and decrease soil erosion by minimizing land modification in drylands (Belnap et al., 2011). The environmentally responsible practices in PV installation sites with hydrological and topographical constraints includes the disk-and-roll technique that does not change the existing drainage patterns and macro-level topography (First Solar, 2016). For installation sites without hydrological and topographical constraints, the mowing technique is preferable to traditional land grading, as this leaves the root structure of grasses and other species intact and thereby decreases soil erosion. Furthermore, for the utility-scale PV project analyzed in this work, water was used for dust control along with biodegradable palliatives when soil and wind conditions were favorable to saltation effects and water proved ineffective. The dust control measures are important, as the project is located in the Mojave Desert where the dominant soil type is aridisols (United States Department of Agriculture, 2016a) and this region is a significant dust source in North America (Prospero et al., 2002). The particulate emissions from soil disturbance during the PV installation phase, as in other construction projects (Muleski et al., 2005; Ketchman and Bilec, 2013), can result in negative environmental impacts (Gilchrist and Allouche, 2005; Russell and Brunekreef, 2009). Studies have linked PM exposure to cardiovascular, respiratory, and reproductive health issues, and PM emissions at the work environment and urban locations pose significant worker and public health and safety risks (Brunekreef and Forsberg, 2005; Duvall et al., 2008; U.S. Environmental Protection Agency [EPA], 2009; Wei et al., 2009). To prevent the negative environmental and health impacts, federal, state, and local environmental regulations mandate dust control measures at construction sites (San Joaquin Valley Air Pollution Control District, 2004); EPA, 2012; Maricopa County, 2013). To mitigate environmental and health impacts, project developers implement dust management practices in accordance with regulatory requirements (Guerin, 2017). For example, regulatory requirements for PV project construction in the state of California are managed by the particular air quality district (South Coast Air Quality Management District, 2005) in reference to ambient air quality standards (California Air Resources Board, 2015) .

Wind-driven dust and PM transportation at a utility-scale solar PV project site occurs in three ways: (i) saltation: movement of particles (~100 μm) by a series of short bounces, which further dislodges more particles along the ground; (ii) creep: rolling and sliding of larger particles (~500 μm) along the ground; and (iii) short- and long-term suspension for particles with a size range of less than ~20 and ~20–70 μm, respectively (Singh, 1994); Kok et al., 2012). The wind velocity at which the gravitational and interparticle cohesive forces are overcome and saltation or wind erosion is initiated is called the threshold friction velocity (u_*) (Shao and Lu, 2000). For particles with size greater than 100 μm, u_* is directly proportional to the square root of the particle size (Bagnold, 1941). The complexity in calculating u_* increases for particle sizes smaller than 100 μm, and this is discussed in Greeley and James (1985) and Shao and Lu (2000). For wind velocity greater than this threshold, the rate at which soil particles are dislodged is directly proportional to the cube of the wind speed (Chepil, 1945; Morgan, 2009). Therefore, a reduction in wind velocities due to shielding effects of built structures will significantly reduce the dust emissions. Rooftop- and ground-mounted PV deployments have demonstrated wind-shielding effects in field conditions and in simulations where wind velocity at back row of panels is lower than that measured at the first row (Chepil, 1945; Morgan, 2009).

Existing research based on simulations and laboratory-scale wind tunnel studies have analyzed the impacts of dust and wind loads on the performance of PV systems, and wind shielding by PV installations (Chevalier and Norton, 1979; Shademan and Hangan, 2009); Pavan et al., 2011; Ketjoy and Konyu, 2014). Although these studies have advanced understanding of the underlying physical processes that can impact the PV electricity generation profile, there has been no comprehensive assessment of the dust mitigating potential of large-scale utility-scale PV installations. Pui et al. (Pui et al., 2014) discussed the use of solar PV panels on wind break walls to reduce emissions entering China without presenting any data or preliminary results and proposed further research to evaluate the impact of dust, local weather conditions, electricity storage, and transport requirements for successful deployment of PV panels as wind shields. With no scientific clarity to inform PV industry stakeholders on the dust impacts of PV installation, the current industry practice for post-construction dust monitoring can range from no monitoring requirement to a 3-yr requirement (U.S. Department of the Interior Bureau of Land Management, 2010) to an upper bound of 25 yr (full lifetime of the PV installation). This time-based monitoring fails to disaggregate background from project-related dust emissions and differences in dust

emissions observed during and after construction. Dust emissions typically increase during the construction phase and decrease with the completion of construction when disturbances to the land stop and due to wind-shielding impacts of PV panels. Therefore, dust emissions can reduce significantly even before the stipulated dust monitoring time frame ends, and extended monitoring requirements can add to the economic cost of PV electricity generation without a measurable health or environmental benefit.

With PV installations being installed across diverse geographical, soil, and wind conditions, there is a critical need to investigate if the wind-shielding properties of PV installations reduces dust and particulate matter (PM) emissions during and after construction. A quantification of a reduction in PM emissions from large utility-scale PV installations can inform environmental regulators and PV project management practices, reduce the monitoring time frame requirements and the associated monitoring costs, and improve the environmental health and safety aspects of future PV deployments in geographies with a high incidence of dust and PM emissions.

To address the above knowledge gaps, this study contains novel research that (1) presents 3-yr PM concentration data from field observations at a 550-MW_{AC} utility PV project; (2) disaggregates construction from post-construction PM data based on the PV project construction timelines; (3) evaluates the hypothesis that utility-scale PV installations in a desert environment can decrease the downwind PM concentration over time through a wind-shielding effect; and (4) demonstrates a reduction in PM concentration levels post installation when compared with background concentration levels.

Materials and methods

Utility photovoltaic project and particulate matter monitoring setup

The Desert Sunlight solar project installed a total capacity of 550 MW_{AC} of thin-film cadmium telluride (CdTe) PV systems from September 2011 to November 2014 in Riverside County, California. The project was developed by First Solar and is co-owned by NextEra Energy Resources, GE Energy Financial Services, and Sumitomo Corporation of America and is estimated to displace 300,000 tons of carbon dioxide (CO_2) annually (First Solar, 2015). The PM data were collected using a beta attenuation monitor (BAM) during and after construction of the PV plant from February 2012 to September 2015. Four BAMs were installed in the north, south, east, and west locations at the edge of the site boundary to record PM concentrations. BAMs were chosen because previous studies have shown them to accurately monitor PM on a real-time basis and meet regulatory requirements (Chung et al., 2001; Solomon and Sioutas, 2008). The site plan for the project with the locations of the four BAMs is presented in Figure 1.The PM inlet height for the BAM stations is 1.2 m. The solar panels have dimensions of 1.2 m in length by 0.6 m in width, mounted in a landscape orientation and tilted at 22.5° angle, with four rows of panels in each array. The lower and upper edges of the array are 0.45 and 1.42 m from the ground level. The row-to-row spacing (distance between two consecutive posts on which arrays are mounted) is 4.1 m. The construction proceeded in the south–north direction, with the first block energized on 19 December 2013 and the entire plant operational by 1 December 2014. BAM monitors (Met One Instruments, 2015) collected the $PM_{2.5}$ and PM_{10} data and co-located weather stations measured wind direction, date, and time (NextEra Energy Resources, 2015). The wind direction and PM data were recorded on a minute and an hourly basis, respectively. The wind direction readings in the four BAMs were mapped to sixteen standard directions corresponding to sixteen 22.5° portions in a 360° wind compass. By convention, in this study, the BAM readings represent the direction to which the wind is blowing. For example, the "E" reading in the BAM represents a wind blowing to the east at an angle between 78.25° and 101.25°. This convention, which is opposite that of the standard practice (United States Department of Agriculture, 2016b), was chosen to be consistent with the convention used to report the wind direction data recorded by the BAM (NextEra Energy Resources, 2015).

The wind direction data were available on a minute-level resolution, and to match them with the hourly PM data, we calculated the average of all the angle values recorded in 1 hr (Section S1 in Supplemental Materials). In cases when wind direction is highly variable, the use of hourly arithmetic mean may mask some of the variability in the underlying wind direction data.

PM data disaggregation

To analyze if PV installations decrease downwind PM concentrations through a wind-shielding impact, the PM readings from the four BAMs (Table 1)were separated into three groups: (1) Background: This group includes PM readings when the BAM is upwind of the PV installation. For example, at the north BAM station, the PM readings for the SSE, S, and SSW blowing winds are categorized as background, as these winds blow away from the north BAM station in a north–south direction and are not affected by the PV

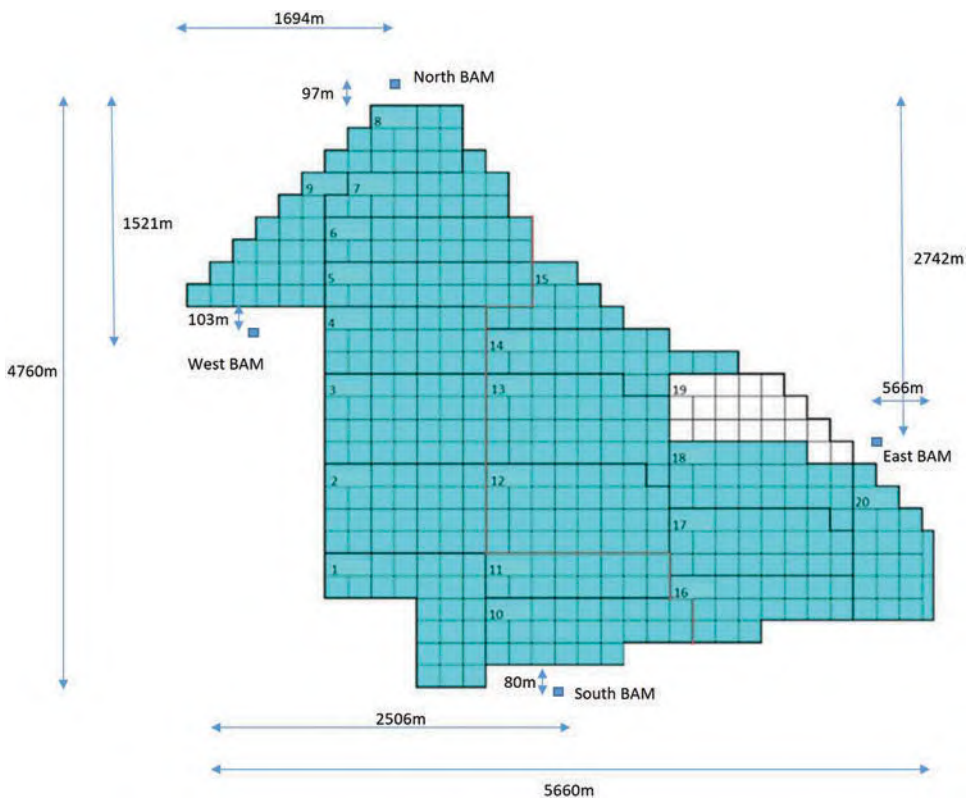

Figure 1. Site map showing the PV block numbers and the locations of the four beta attenuation monitors (BAMs) that recorded the $PM_{2.5}$ and PM_{10} readings.

Table 1. Sample sizes, means, and standard deviations for the three groups of $PM_{2.5}$ and PM_{10} concentration readings at the four BAM stations.

PM fraction	BAM station	Group	Mean	Standard deviation	Sample size
$PM_{2.5}$	West	Background	0.005	0.02	2913
		Construction	0.005	0.007	2713
		Post-construction	0.003	0.003	650
	East	Background	0.006	0.011	2962
		Construction	0.006	0.015	1705
		Post-construction	0.003	0.003	272
	North	Background	0.006	0.01	2962
		Construction	0.004	0.004	2962
		Post-construction	0.002	0.002	549
	South	Background	0.006	0.01	973
		Construction	0.007	0.01	2640
		Post-construction	0.006	0.004	390
PM_{10}	West	Background	0.017	0.04	2962
		Construction	0.01	0.03	2822
		Post-construction	0.013	0.014	838
	East	Background	0.02	0.04	2962
		Construction	0.019	0.036	1864
		Post-construction	0.01	0.019	318
	North	Background	0.02	0.02	2962
		Construction	0.012	0.02	2962
		Post-construction	0.01	0.018	780
	South	Background	0.01	0.038	1181
		Construction	0.024	0.041	2962
		Post-construction	0.021	0.038	968

installation. This group includes the readings for all the days for which PM readings are recorded by the BAM. (2) Construction: This group includes PM readings when the BAM is downwind of the PV installation. For example, at the north station, the PM readings for the NNE, N, and NNW blowing winds are categorized as construction, as these winds blow towards the north BAM station in a south–north direction and are affected by the PV installation (see Figure 1). The construction group includes only those PM readings

through the last day of construction, 30 November 2014. (3) Post-construction: PM readings were included in this group based on the same conventions used in the construction group (BAM downwind of PV installation). PM readings were included from 1 December 2014, as this corresponds to the start of full operation after completion of construction.

The conventions used for the wind directions and the corresponding categorization of background, construction, and post-construction of PM readings at each of the four BAM stations are summarized in Section S2 in Supplemental Materials).

Statistical analysis of particulate matter concentration

To investigate if the PM concentrations decreased after PV system installations, this study initially considers a time-series analysis of the construction and post-construction readings from February 2012 to September 2015. A linear trend line was generated for the construction and post-construction $PM_{2.5}$ and PM_{10} data (Figure 2). The objective of the temporal analysis is to evaluate the expectation that as the PV installation progresses, wind velocities can be reduced due to shielding effects of the built structures, resulting in lower downwind PM concentrations. To more quantitatively evaluate this hypothesis, a statistical comparison of grouped data has been conducted using confidence interval plots (at 95% confidence) of the mean background, construction, and post-construction $PM_{2.5}$ and PM_{10} concentration readings at the four BAM stations (Figure 3).

The choice of tests to investigate the statistical significance in the difference between the groups depends on whether the data are parametric or nonparametric. We chose the Anderson-Darling (AD) test for normality (Anderson and Darling, 1954; Razali and Yap, 2011).

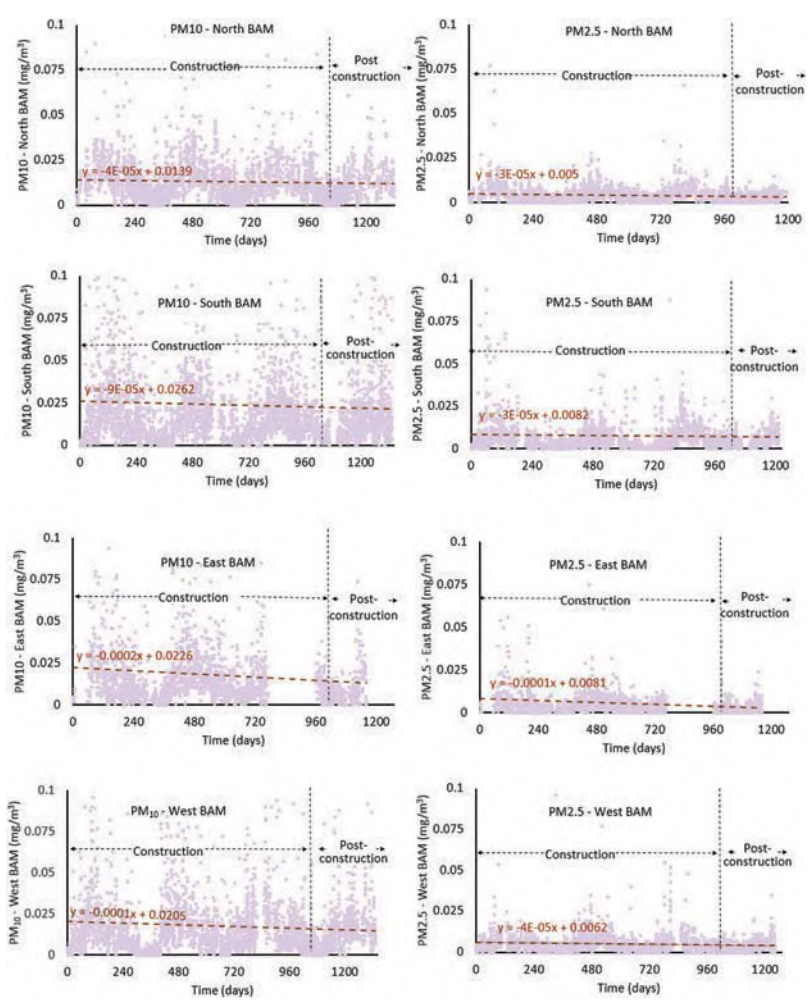

Figure 2. Time series and the corresponding linear trend equations for $PM_{2.5}$ and PM_{10} concentrations at the four BAM stations for the construction and post-construction groups. The zeroth day, by convention, represents the first day of recording PM_{10} concentrations after the start of construction.

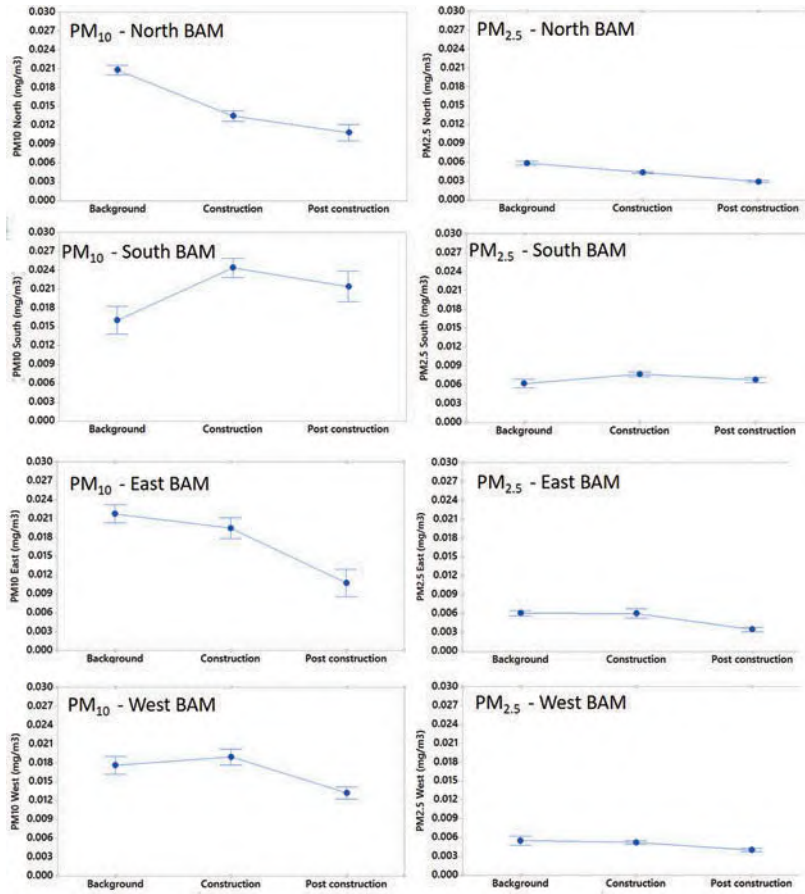

Figure 3. Confidence interval (at 95%) plots depicting the mean $PM_{2.5}$ concentration levels for the background, construction, and post-construction groups recorded at the four BAM stations.

This test calculates a probability value (P value) from the data to accept ($P > 0.05$) or reject ($P \leq 0.05$) a null hypothesis that states that the data are normally distributed. The results showed that the underlying distribution for $PM_{2.5}$ and PM_{10} readings of the three groups for all the four BAM stations was not normal (Section S3 in Supplemental Materials). Furthermore, to verify if the PM data can be transformed (from a lognormal distribution) into a normal distribution, the Box-Cox transformation (Box and Cox, 1964) was applied, and a subsequent AD test showed that the transformed data were not normally distributed (Section S4 in Supplemental Materials). After demonstrating that the data were nonparametric, we chose the Kruskal-Wallis (KW) (Shao and Lu, 2000; Singh, 1994) test to evaluate the statistical significance in the difference between two or more groups of nonparametric data. The KW test calculates a P value from the data to accept ($P > 0.05$) or reject ($P \leq 0.05$) a null hypothesis that states that the difference between the groups is not statistically significant.

The hypotheses to evaluate if the $PM_{2.5}$ and PM_{10} concentrations in the background, construction, and post-construction groups are significantly different are as follows:

H_{null}: No statistically significant difference between the three groups (background, construction, and post-construction) for $PM_{2.5}$ or PM_{10}

$H_{alternate}$: Statistically significant difference between the three groups (background, construction, and post-construction) for $PM_{2.5}$ or PM_{10}

The KW test only verifies if the differences in the medians of the three PM groups are statistically significant and does not rank the groups based on their median values (Elliott and Hynan, 2011). The nonparametric Dunn's multiple comparison post hoc test with the Bonferroni correction(Dunn, 1964) was chosen to identify groups with significantly different median PM concentrations and rank the three groups based on the median values. If the corrected P value returned by the Dunn's multiple comparison test for the PM concentrations of two groups is less than 0.05, then there is a significance difference between the two groups. In this case, if the difference between the rank scores of the PM concentrations of the two groups is negative, then the second group's PM concentration is statistically

higher than the first group. Similarly, if the difference is positive, then the first group's PM concentration is statistically higher than that of the second group.

The KW and the Dunn's multiple comparison tests were executed using the JMP software (SAS, 2016), and the Anderson-Darling test and the Box-Cox transformation were performed using the Minitab package (Minitab, 2016).

Results and discussion

The linear trend equations (Figure 2) are calculated from the values recorded by the BAM stations, which have a range of 0–0.9 and 0–0.5 mg/m^3 for PM_{10} and $PM_{2.5}$, respectively. The graphs are restricted to the 0–0.1 and 0–0.05 mg/m^3 ranges for PM_{10} and $PM_{2.5}$, respectively, to clearly depict the downward slope of the linear trend lines. The negative slope of the linear trend lines in the time series (Figure 2) indicates that the PM_{10} and $PM_{2.5}$ concentrations decrease with time as the project progresses toward the completion of construction and enters the post-construction phase, consistent with increased wind-shielding effects of the built structures. As this trend could also be related to the decrease in ground-disturbing activities as construction approaches completion, a statistical comparison of post-construction downwind PM data with background data has also been conducted, to evaluate whether post-construction PM levels are lower than both construction and background levels.

The confidence interval plots of the three groups (Figure 3) show that mean PM_{10} and $PM_{2.5}$ concentration levels in the post-construction group are lower than those in the construction group and the post-construction concentrations are lower than the background concentrations for the east, west, and north BAM stations. Furthermore, the intervals of the mean concentrations during the construction phase overlap with or are lower than the background concentrations for the east, west, and north BAM stations. The wind-shielding effect is only partially in place during the construction time frame, as part of the site has been constructed whereas other parts have not. Use of water and palliatives limits on-site dust generation during construction, but the construction PM concentration has the potential to be higher than background level because of the construction activities, as is the case for the south BAM station. For the same land management practices during project construction, the differing results between BAM stations may be related to the relatively higher background PM_{10} concentrations in the north and east BAM stations. Differences in background PM concentrations between the BAM stations are likely influenced by the topography surrounding the project site and associated surface features such as nonerodible surface material, vegetation cover, mineralized soil crusts, and biological soil crusts (U.S. Department of the Interior Bureau of Land Management, 2011).

In Table 2, for each of the BAM stations, the KW test returns a P value of <0.001; therefore, the null hypothesis (H_{null}) is rejected ($P < 0.05$), demonstrating statistically significant differences between the three groups (background, construction, and post-construction) for $PM_{2.5}$ and PM_{10} concentration levels at the four BAM stations.

The post hoc analysis results (Table 3) confirm the trends in the time-series analysis and the confidence interval plots that show that the PM_{10} and $PM_{2.5}$ concentration levels in the post-construction group are lower than in the construction group and the post-construction concentrations are lower than the background concentrations for the east, west, and north BAM stations (Figure 3). The conclusion column in Table 3 shows that the PM_{10} concentrations peak during construction in the west and south

Table 2. Kruskal-Wallis test results demonstrating statistically significant differences between the median background, construction, and post-construction $PM_{2.5}$ and PM_{10} concentrations in each BAM station at a 95% confidence interval.

		PM_{10}		$PM_{2.5}$	
BAM station	Group	Median concentration (mg/m^3)	P	Median concentration (mg/m^3)	P
West	Background	0.011	<0.001	0.004	<0.001
	Construction	0.011		0.004	
	Post-construction	0.009		0.003	
East	Background	0.012	<0.001	0.004	<0.001
	Construction	0.012		0.004	
	Post-construction	0.007		0.003	
North	Background	0.014	<0.001	0.005	<0.001
	Construction	0.009		0.003	
	Post-construction	0.008		0.003	
South	Background	0.009	<0.001	0.004	<0.001
	Construction	0.016		0.006	
	Post-construction	0.013		0.006	

Table 3. Results of the nonparametric post hoc analysis to rank the background, construction, and post-construction $PM_{2.5}$ and PM_{10} concentrations from the four BAM stations.

BAM station	Comparison	PM_{10} Score mean difference	PM_{10} *P*	$PM_{2.5}$ Score mean difference	$PM_{2.5}$ *P*	Conclusion (ranking of PM_{10} and $PM_{2.5}$ mean concentrations)
West	Construction − Background	137.1	0.0245	164.11	0.019	PM_{10}: Construction > Background > Post-construction
	Post-construction − Background	−324.83	0.0001	−247.31	0.0047	$PM_{2.5}$: Construction > Background > Post-construction
	Post-construction − Construction	−461.93	<0.0001	−411.43	<0.0001	
East	Construction − Background	−86.39	0.1642	−105.56	0.0448	PM_{10}: Background > Construction > Post-construction
	Post-construction − Construction	−925.23	<0.0001	−607.5	<0.0001	$PM_{2.5}$: Construction > Background > Post-construction
	Post-construction − Background	−1011.62	<0.0001	−713.02	<0.0001	
North	Post-construction − Construction	−735.77	<0.0001	−878.11	<0.0001	PM_{10}: Background > Construction > Post-construction
	Construction − Background	−1335.14	<0.0001	−677.8	<0.0001	$PM_{2.5}$: Construction > Background > Post-construction
	Post-construction − Background	−2070.91	<0.0001	−1555.91	<0.0001	
South	Construction − Background	804.39	<0.0001	451.37	<0.0001	PM_{10}: Construction > Post-construction > Background
	Post-construction − Background	603.92	<0.0001	516.12	<0.0001	$PM_{2.5}$: Construction > Background Post-construction > Background No statistically significant difference between construction and post-construction mean $PM_{2.5}$ concentrations
	Post-construction − Construction	−200.47	0.0007	64.74	0.9	

BAMs and similarly the $PM_{2.5}$ concentrations peak during the construction in the west, east, north, and south BAMs. There is a subsequent decrease in the post-construction group in all these cases. For the south BAM, the median post-construction PM_{10} and $PM_{2.5}$ concentrations are greater than the background concentrations by 0.004 and 0.002 mg/m^3, respectively, which represent marginal increases of 2.6% and 5.7% when compared with EPA's 24-hr ambient air quality standards of 0.15 and 0.035 mg/m^3 for PM_{10} and $PM_{2.5}$, respectively (EPA, 2015). In the case of $PM_{2.5}$ measurements for the south BAM, the marginal increase in post-construction concentrations compared with background concentrations is not statistically significant (Table 3). For the south BAM, PM measurements may have been affected by emissions from traffic on an access road that originates near the southwest corner of the site or a drainage berm near the south station.

These results indicate statistically significant reductions in the downwind post-construction PM concentrations in six out the eight cases ($PM_{2.5}$ and PM_{10} concentrations in north, east, and west stations) when compared with the background concentrations. These observations are consistent with the wind-shielding impact of PV systems after the completion of construction. Other factors that can potentially impact PM emissions are humidity, rainfall, local vegetation, and the turbulence due to the wind flow interaction with the PV panel (Chepil, 1945; Singh, 1994; Kok and Renno, 2009; Morgan, 2009; Kok et al., 2012; Etyemezian et al., 2017). The PV panels interact with moisture or water due to humidity and rainfall, and this changes the water deposition patterns on the ground (Cook and McCuen, 2013; Luo et al., 2017) and the resulting PM emissions when compared with a scenario with no PV installations. The increase in PM emissions from the loss of ground vegetation will gradually recede as the ground vegetation recovers when land disturbance ceases after the completion of the PV construction phase. Future research investigating the impact of these factors on PM emissions before and after a PV installation can further strengthen and complement this study.

The post-construction PM concentrations are reduced to below the background levels (Table 3) for six out of the eight cases within a 10-month post-construction observation period (refer to post-construction start and last dates in Table S2, Section S2 in Supplemental Materials), and with construction activity having ceased and no further ground-disturbing activities, the PM emissions are expected to remain stable. Therefore, the need for post-construction monitoring of downwind PM levels may be reduced when PV systems are deployed under similar topographical and weather conditions. The findings demonstrate that by restricting monitoring time frames to 1 yr from the completion of construction (under similar soil and weather conditions) rather than the current requirement of 3 yr (U.S. Department of the Interior Bureau of Land Management, 2010), the monitoring costs and thereby the economic costs of PV electricity generation

can be further reduced. Furthermore, based on the findings of this study, future research can investigate the health impacts from PM emission reductions (Brunekreef and Forsberg, 2005; Duvall et al., 2008; EPA, 2009; Wei et al., 2009) for PV projects located in desert conditions and in the vicinity of populated areas. The results of this study are based on the desert conditions that are typical to utility-scale PV installations that are increasingly located in the southwest United States (Hernandez et al., 2014). Additional PM monitoring in other locations can assess the wind-shielding effect under different soil, topographical, and weather conditions.

Conclusion

This research evaluates the impact of a utility-scale PV installation on downwind $PM_{2.5}$ and PM_{10} concentrations based on readings collected from four BAMs over 3 yr at a 550-MW_{AC} plant in Riverside Country, California. The post-construction downwind $PM_{2.5}$ and PM_{10} concentrations are lower than the background concentrations for readings collected from three of the four BAMs. The reduction in PM concentrations can be attributed to the wind-shielding effect of the PV installation. The fourth BAM recorded 0.004 and 0.002 mg/m^3 marginal increases in post-construction $PM_{2.5}$ and PM_{10} concentrations when compared with background concentrations, respectively, and these increases correspond to 2.6% and 5.7% of the 24-hr ambient air quality standards defined by the EPA. The reductions in the PM concentrations in the three BAM stations were observed within 10 months of completion of construction; therefore, the need for post-construction monitoring of downwind PM levels may be reduced from 3 to 1 yr for deployments in locations with topographical and weather conditions similar to Riverside County, California.

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BARRON-GAFFORD RESEARCH GROUP
BIOGEOGRAPHY - ECOSYSTEM SCIENCE

Response to Technical Queries Associated with Permit NO: 2017-301
for the Proposed Solar Farm at:
1190 and 1220 Cosgrove-Lemnos Road,
260 Tank Corner East Road,
875 Boundary Road and
85 Crooked Lane LEMNOS VIC 3631

STATEMENT OF EVIDENCE BY GREG BARRON-GAFFORD ON SOLAR HEAT ISLANDING ISSUES

Prepared for Neoen Australia Pty Ltd

MAY 2018

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1 INTRODUCTION: PRACTICE NOTE – EXPERT EVIDENCE

Name and Address of Expert

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School of Geography & Development;
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Qualifications of Expert

PhD, Ecosystem Ecology, University of Arizona, 2010
MS, Natural Resources & Ecology, University of Georgia, 2001
BS, Environmental Science, Texas Christian University, 1998
Member, American Geophysical Union
Member, Ecological Society of America
Member, American Association of Geographers
Refer Curriculum Vitae at Attachment 1.

I have authored or co-authored 71 peer-reviewed publications that have been cited more than 1,900 times, and I have led research in ecosystem ecology and plant-atmosphere interactions for more than 17 years. I maintain an active research program in assessing the impacts of land use and climatic change in terms of plant function, ecosystem response, and local climate conditions. My team, under my supervision, produced the first experimental and empirical examination of the presence of a heat island effect associated with PV power plants.

Any Private or Business Relationship between the Expert Witness and the Party for Whom the Report is Prepared

None.

Instructions

Written instructions from White & Case Lawyers acting on behalf of Neoen Australia Pty Ltd dated 16 April as follows:

"*We would like you to prepare an expert witness statement for the panel in which you:*

(a) set out your background and expertise relevant to this issue;

(b) provide further information in relation to the Arizona study the subject of the paper that you co-authored titled The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures published in Nature Scientific Reports on 13 October 2016. In particular, we ask that you detail the following:

> *(i) brief description of study methodology;*
>
> *(ii) radius of the measured heat effects in that study, including those that were not outlined in the final paper. Explain the editing process that resulted in measured effects being excluded from study;*
>
> *(iii) analysis of your conclusions around the measured effects, including simple descriptions of energy pathways relevant to the 'heat island effect';*
>
> *(iv) outline contextual factors that may be relevant to the 'heat island effect', including environmental factors such as local landscape, humidity, cloud cover, fixed or rotating tilt panels, etc; and*
>
> *(v) briefly comment, if possible, on your understanding of the possible effect of wind on the heat island effect.*

(c) comment on your findings to date in other research work that you have been involved with relating to the PVHI effect and co-location of photovoltaics and agriculture;

(d) comment on the general implications of the above studies and literature for the Project and the interface between it and any established or future agricultural uses. Where possible, please include:

> *(i) comparative characteristics of the Arizona and Shepparton sites (e.g. presence of vegetation);*
>
> *(ii) your opinion as to whether the Project would change any onsite or offsite temperature;*
>
> *(iii) associated with that, your opinion as to how any change, if identified, would impact on bird and insect populations in the area;*
>
> *(iv) mitigating factors or measures that exist or could be implemented.*

We would also like you to consider the objections to the Project that are relevant to your area of expertise and respond to any relevant matters in your witness statement."

Facts, Matters and Assumptions

Facts, matters and assumptions on which opinions expressed in the report are based are set out in the report.

Documents and Materials Taken Into Account

The documents and any literature or other materials taken into account in preparing the report are identified in the report.

Methodology to prepare Witness Statement

In preparing this expert report I developed the following process:

(*i)* I reviewed the application and noted the submissions raising concerns about the potential negative impacts of the proposed solar farm on neighboring properties, environmental conditions, and birds, pollinators and other insects.

(*ii)* I reviewed the scientific literature on PVHI and collated the findings.

Examinations, Tests and Investigations

All examinations, tests, and investigations have been undertaken by me.

Summary of Opinion

A summary of opinion is included in the Conclusion.

Provisional Opinion

There are no provisional opinions.

Relevant Questions Outside of Expertise

There are no matters of relevance outside of my expertise.

Whether the report is incomplete or inaccurate in any respect

As far as I am aware the report is not incomplete or inaccurate in any respect.

Declaration

I have made all the inquiries that I believe are desirable and appropriate and no matters of significance, which I regard as relevant, have to my knowledge been withheld from the Panel.

2 MY WORK ON THE PHOTOVOLTAIC HEAT ISLAND (PVHI) EFFECT

2.1 Background and Expertise Relevant to Solar Projects

I have led a team from January 2013 to present to assess the impacts of land use for renewable energy production in terms of plant function, ecosystem response, and local climate conditions. My colleagues in this work include faculty and students from the Department of Physics and Atmospheric Science and from the Department of Hydrology at the University of Arizona. We took continuous measurements (described below) for more than 18 months, and I then led a publication of the results in a co-authored, peer-reviewed manuscript entitled *The Photovoltaic Heat Island Effect (PVHI): Larger solar power plants increase local temperatures* published in ***Nature Scientific Reports*** on 13 October 2016. The paper details an objective look at the degree to which a PV power plant might alter local climate conditions. The paper is attached at Annexure 2. The study was conducted in response to requests from the Pima County (Arizona) Chief Building Official for Development Services for an assessment of the potential for a PVHI beyond the few studies previously presented in the literature.

2.2 Further Information on the Published Study of the Photovoltaic Heat Island (PVHI) Effect in Arizona

Brief description of methodology used to determine the presence of a PVHI within a solar farm

Early work on the detection of the presence of a PVHI in solar farms has been mostly theoretical or based upon simulated models. Furthermore, past empirical work had been limited in scope to a single biome. In order to determine whether or not a PV array elevated ambient air temperatures (°C) relative to native surroundings, we used shaded and aspirated temperature probes 2.5 m (manufacturer details can be found in *Barron-Gafford et al. (2016)*; Figure 1) at the following representative sites, all within a 1km^2 area:

- natural landscape (semiarid desert ecosystem);
- PV solar farm, where the probe was centrally located within the PV array; and
- within a traditional built environment (parking lot and commercial buildings).

Temperature probes were cross-validated for precision (closeness of temperature readings across all probes) at the onset and the conclusion of the experiment. We set the dataloggers to save the measurements of temperature at 30-minute intervals throughout a 24-hour day. We installed the weather stations in April 2014 and began simultaneously monitoring the three sites throughout an entire yearlong cycle to capture variations in temperatures across seasonal periods. We defined a PVHI effect as the difference in ambient air temperature between the PV solar farm and the natural landscape.

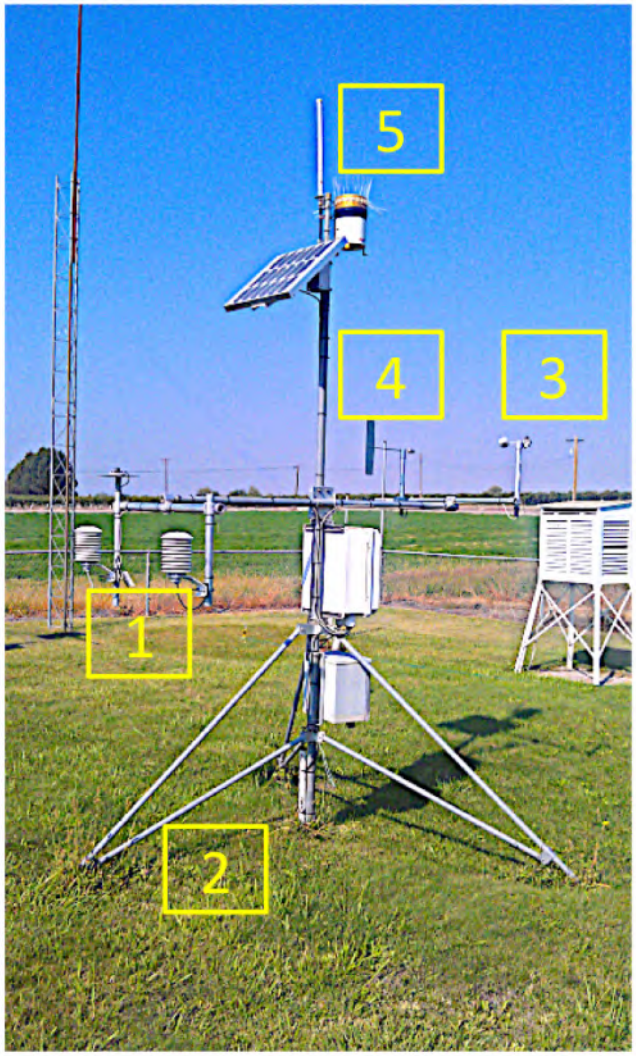

Figure 1. Weather stations were used to measure the local microclimate of an area. Each weather station used captured (1) ambient air temperature, (2) soil temperature, (3) wind speed, (4) wind direction, and (5) precipitation. All data were monitored every 30 minutes, and average conditions were saved by the datalogger. Cumulative precipitation was summed for each 30 minute period.

This type of weather station was installed at each of three sites: the photovoltaic array of a solar farm, the natural landscape, and a parking lot, to represent a typical built environment.

Photo credit: Campbell Scientific Instruments

Results illustrating the presence of a PVHI within a solar farm

Ultimately, we found that air temperatures within a PV solar farm are higher than those in nearby natural settings, and we referred to this as the PVHI effect (Figure 2). We found the PVHI effect to be much greater within the solar farm at night, with the greatest impacts being within the spring and summer months. Additionally, we found that presence of a PVHI effect to be much less significant during the day, and that the effects were least prominent in the winter and fall, regardless of time of day.

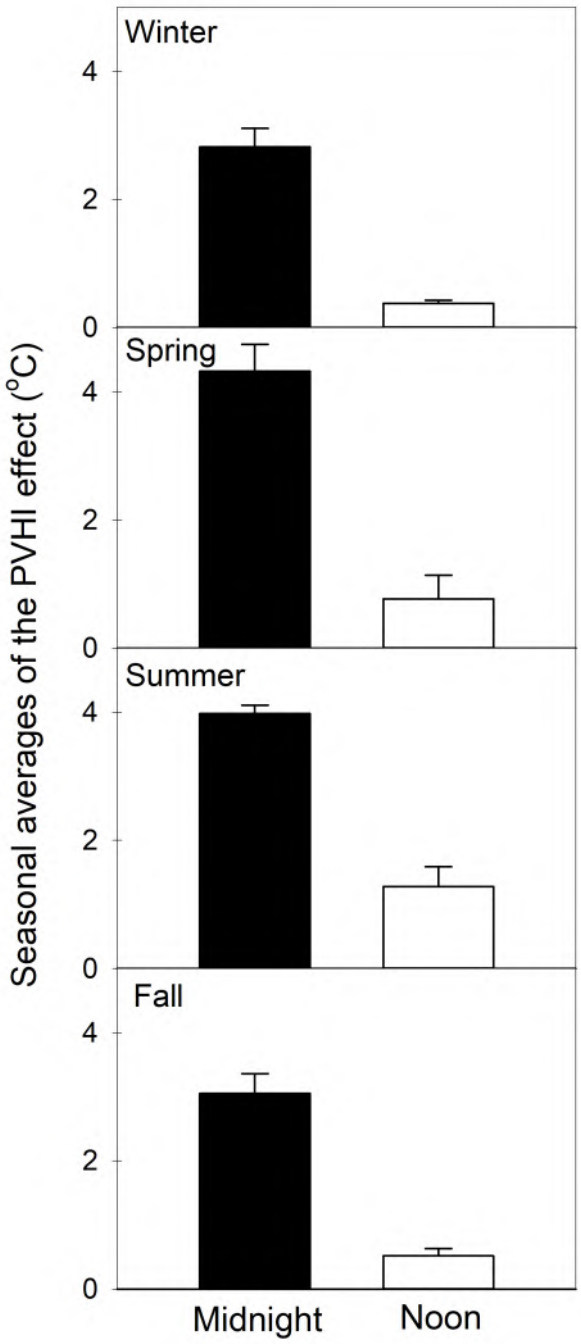

Figure 2. Through continuous monitoring of air temperatures within the center of a solar field for more than a year, we detected the presence of a PVHI effect. The effect was greatest in the nighttime hours (black bars indicate averages at midnight) and lowest during the day (white bars). The degree of the PVHI effect in the center of the solar farm was also seasonally variable with the warm season months experiencing greater impacts than the cool season months.

Figure recreated from Barron-Gafford et al. (2016).

Analysis of conclusions on the presence of a PVHI within a solar farm

As described in *Barron-Gafford et al. (2016*; in Annexure 2), incoming sun energy typically is either reflected back to the atmosphere or absorbed, stored, and later re-radiated in the form of latent or sensible heat. Within natural ecosystems, vegetation reduces heat gain and storage in soils by creating surface shading; this also occurs within PV arrays, but less so in the rows between the panels. Energy absorbed by vegetation and surface soils can be released as latent heat in the transition of liquid water to water vapor to the atmosphere through water loss from soils (evaporation) and vegetation (transpiration). This heat-dissipating latent energy exchange is dramatically reduced within a PV installation that does not have an "understory" of vegetation. PV panels convert ~20% of absorbed energy into usable electricity and also allow some light energy to pass, which, in unvegetated soils will lead to greater heat absorption. This greater sensible heat efflux from the soil becomes trapped under the PV panels, much like clouds trap the energy radiating from the Earth's surface. On cloudy nights, air temperatures do not cool off as much as they do on clear nights. This is the same principle in the PVHI, and I believe the reason that the PVHI dissipates so quickly as one moves away from the edge of the panels. Under the panels, it is analogous to a cloudy night, and away from the array, where those panels are absent, conditions are analogous to a clear night sky.

2.3 Determining the Spatial Extent of the PVHI

Methods for measuring the radius of the measured heat effects in the study

In addition to measuring the degree of the photovoltaic heat island (PVHI) effect within the solar farm, we measured the extent to which the heat island effect extended outward from the PV array (Figure 3). We installed the weather stations with the same air temperature probe described in Section 2.2 to measure temperature:

- inside the array at 20m and 40m in from the edge of the array;
- at the edge of the array (0m); and
- outside the array at 10, 20, 30, 40, and 50m out from the edge of the array.

We installed these weather stations in April 2015, and we maintained them throughout a six-month period to capture variation in the relative differences in temperatures across seasonal periods. While this was a part of our original study design once we had identified the presence of the PVHI effect, this data and associated graphic were cut from our final manuscript by the *Nature Scientific Reports* editor due to space constraints. This is quite unfortunate because the distance of the PVHI effect is one of the primary questions I continue to receive since the publication of this manuscript.

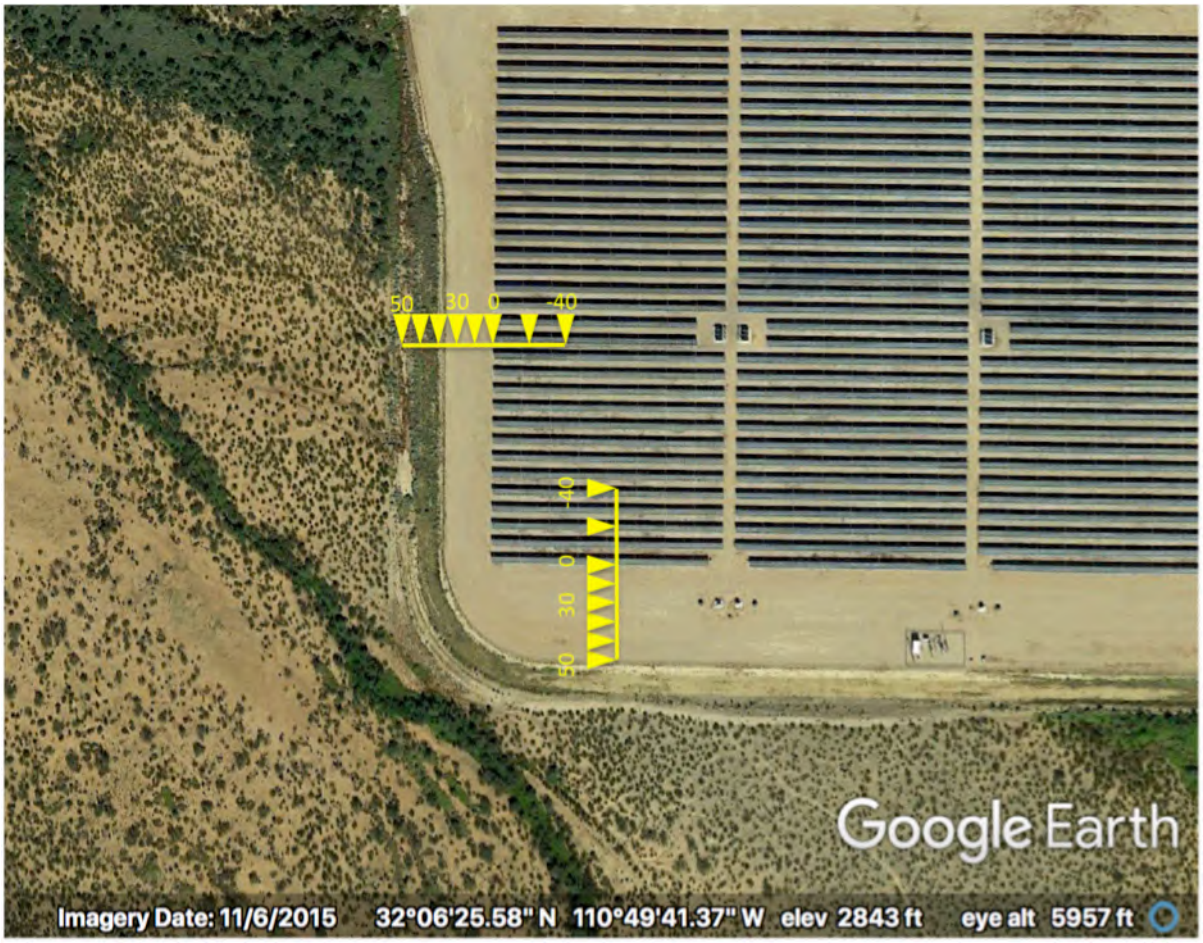

Figure 3. Locations of additional measures of air temperature are marked with yellow triangles. Stations were placed inside the array at 20m and 40m in from the edge of the array, at the edge of the array (0m), and outside the array at 10, 20, 30, 40, and 50m out from the edge of the array to quantify the spatial extent of the PVHI effect.

Results on the radius of the measured heat effects

We found that the PVHI was indistinguishable from air temperatures over native vegetation when measured at a distance of 30m from the edge of the PV array (Figure 4). This pattern held true for both daytime and nighttime conditions. Because the PV panels themselves trap the energy from diffuse sunlight that was able to reach the ground underneath them, air temperatures remain elevated within a PV array. As you leave this "overstory" of PV panels, energy is able to radiate back towards the atmosphere, as it does in a natural setting, and the PVHI quickly dissipates.

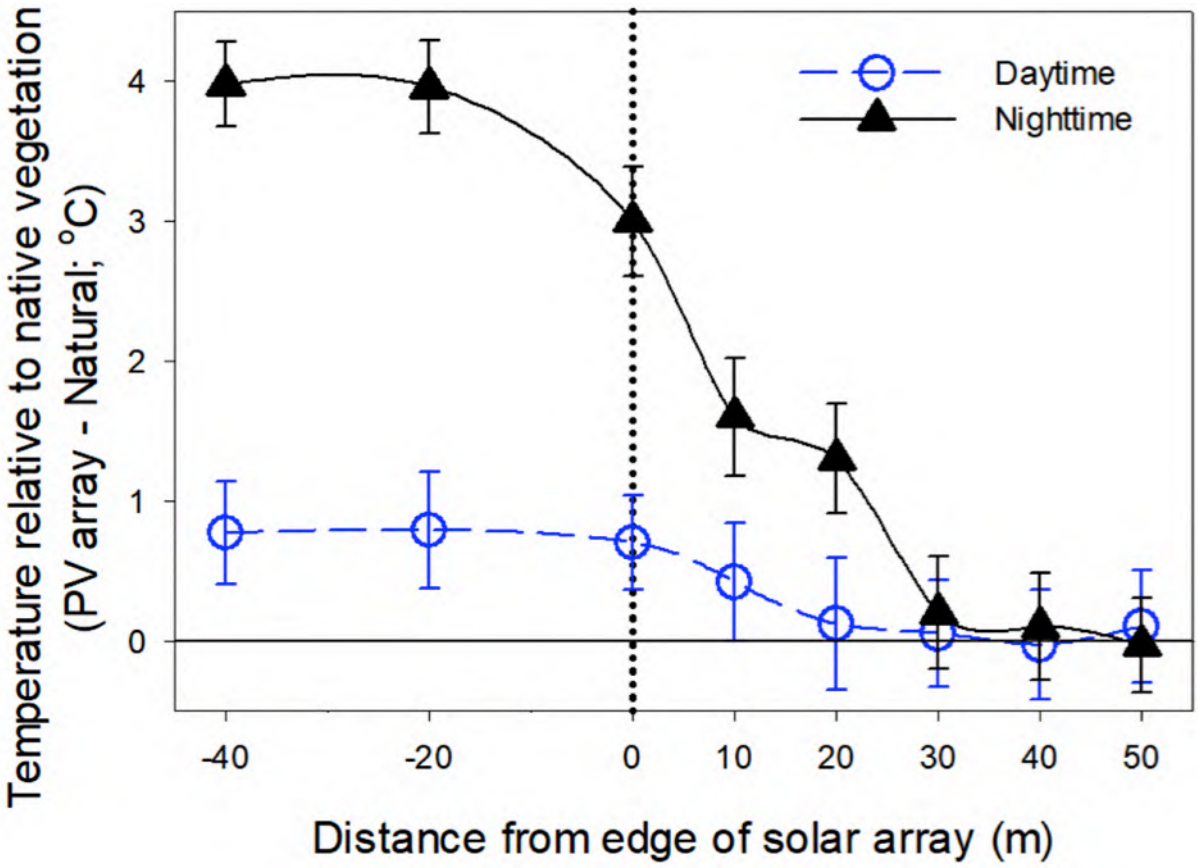

Figure 4. Measures of air temperature within (negative values on the X-axis) and outside of the PV array (positive values on the X-axis) were used to quantify the spatial extent of the PVHI effect. The dotted line represents the edge of the PV array.

The solid line at 0 on the Y-axis illustrates when there is no difference between a measurement along the transect and ambient air temperatures over native vegetation. At night, the PVHI effect of 3-4°C directly above the solar panels is reduced to 1.5 °C at 10m and to 0°C at 30m. There is a lesser PVHI effect by day. Error bars represent 1 standard error around the mean.

3 COMMENT ON THE GENERAL IMPLICATIONS OF THE ABOVE AND OTHER STUDIES IN THE LITERATURE

3.1 CONSIDERATION OF OTHER TECHNICAL PAPERS EXAMINING THE PVHI EFFECT

One of the other primary research articles in the literature on the presence and extent of the PVHI comes from *Fthenakis and Yu (2013)*. This paper links both field data and computational fluid dynamics simulations. Ultimately, *Fthenakis and Yu* found that (*i*) ambient temperatures can be up to 1.9°C greater within a solar farm, and (*ii*) temperatures dissipate rapidly with increased distance from the solar farm, with no detectable effect by at about 300m (Figure 5). In my opinion, the approach and simulations appear sound. However, my critique is tied to the accuracy of the sensors used. For the paper published by *Fthenakis and Yu (2013)*, the accuracy of the Hawk weather station air temperature probe is only ± 0.5°C, but no data on the uncertainty or variation are presented. Please see: https://www.weatherhawk.com/wp-content/uploads/2016/06/Signature-Series-Comprehensive-Manual-V7.pdf

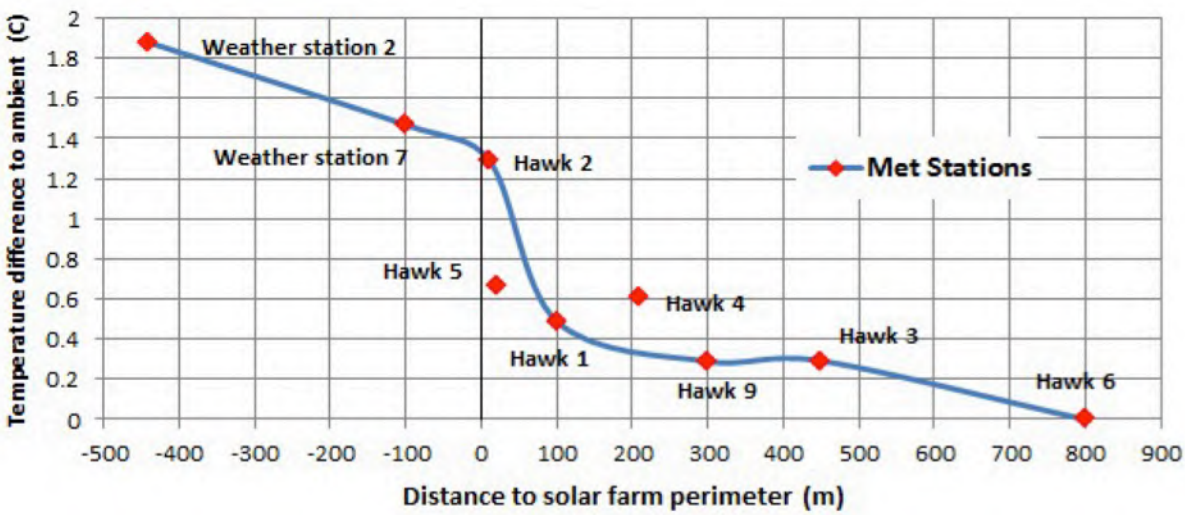

Figure 5. Measures of air temperature within (negative values on the X-axis) and outside of the PV array (positive values on the X-axis), as presented by *Fthenakis and Yu (2013)* to quantify the spatial extent of the PVHI effect. The solid line at 0 on the X-axis represents the edge of the PV array. The data illustrate that the PVHI dissipates rapidly with increasing distance away from the edge of the PV array.

In my opinion, then, if we added this uncertainty to their Figure 8 (shown here as Figure 5 within this report), all measures of air temperature beyond 200m may actually be indistinguishable from ambient air temperatures. Additionally, I do not consider "Hawk 4" to be evidence of a spike in the PVHI away from the PV array. *Fthenakis and Yu* suggest that the higher values at Hawk 4 might be due to the fact that they are on the downwind side of the solar farm. However, I interpret this more as a singular measure that is anonymously higher than those around it, which are on a downward trend as one moves away from the array. Finally, there are no measures of uncertainty on any of these measurements. From maintaining our research sites for more than a year, I know there are day-to-day variations in temperature. *Fthenakis and Yu* also dismiss another one of their sensors as showing "higher temperatures likely due to a calibration inaccuracy", which leads me to wonder if the same might be true for Hawk 4. Taken together, I wonder if this is anything more than an anomaly.

More recently, *Yang et al.* (*2017*) have added an additional manuscript to this body of literature through a detailed suite of measurements on air and soil temperatures at depth. Ultimately, *Yang et al.* found that the degree of PVHI in terms of daytime air temperatures was nearly absent during winter, but during the other seasons the daytime air temperature in the solar farm was higher than that in areas without PV. As in our study, the maximum PVHI effect was detected during their summer. *Yang et al.* found that the PVHI was present during nighttime hours during all four seasons; again this parallels our own research, which examined the seasonal variation in daytime and nighttime PVHI effect. *Yang et al.* did not mention any data on the spatial extent and dissipation of the PVHI effect in their paper.

3.2 CONTEXTUAL FACTORS THAT MAY BE RELEVANT TO THE PVHI EFFECT

To date, no empirical or experimental studies have explicitly examined correlations between environmental factors such as local landscape, humidity, cloud cover, fixed or rotating tilt panels, and either the degree or spatial extent of a PVHI. However, we can look to literature on the analogous Urban Heat Island (UHI) effect and on Human Thermal Comfort (HTC) for potential indicators. Increases in wind speed has been shown to reduce the UHI (*Rajagopalan et al. 2014*), including work conducted

in Australia (*Santamouris et al. 2017*), however, there are less clear patterns in terms of the impacts of humidity on the UHI. Increased cloud cover is likely to exacerbate the PVHI because clouds trap any re-radiation of sun energy back towards the atmosphere, whether in a built or natural environment. Importantly, recent work has shown that the UHI effect is greater in locations with higher background temperatures (*Taha 2017).*

3.3 Possible Effect of PV Angle tilt on the PVHI Effect

To date, no empirical or experimental studies have investigated the impacts of PV panel angle on the degree of PVHI within an array. A greater degree of tilt would allow for greater loss of heat trapped under the panels, but this should be considered in concert with potential reflection from panels at the end of the day, in which a more severe angle might lead to greater horizontal reflection. Our work (*Barron-Gafford et al. 2016*) was conducted within a PV array in which panels pivoted east-to-west tracking the sun, but maximum angles only approached 45°. The work of *Yang et al.* (*2017*), which found a similar contained PVHI effect within a PV array, was conducted within a PV array with panels at a fixed tilt angle of 36°, and the panels within the solar farm studied by *Fthenakis & Yu* (2013) had a tilt angle of 25°. I have been informed that the PV panels in the proposed Project will be single-axis tracking and could, therefore, be left at an angle to dissipate heat overnight. Together, the existing body of research suggests to me that further research on the linkage between PV angle tilt and the degree of the PVHI warrants more study, but I would predict that maintaining a PV panel angle overnight of 45-50° would aid in nighttime dissipation of any PVHI effect that is created within the array.

3.4 Findings Relating to the PVHI effect and Co-Location of Photovoltaics and Restoration or Agriculture (Agrivoltaics)

Grass + Photovoltaics

The notion of “either-or” between green spaces and solar farms has been progressively more challenged in recent years as companies move towards either restoring solar farms with grasses after installation or leaving grasses in place instead of blading the soil during installation. Co-locating grasses under PV arrays

can yield multiple ecosystem services (tangible and non-tangible amenities) including continued carbon dioxide sequestration from our atmosphere, localized cooling from the transpiration of the plants, grazing forage, and storm-water regulation. In my team's own preliminary work on the effects of revegetating PV solar farms with grasses, we found significant cooling of the local atmosphere (Figure 6). In addition to illustrating the positive effect of vegetation on PV solar farm temperatures, the fact that the plants did so well in such close proximity to the PV panels (around and under the panels) suggests to me a lack of a negative impact of PV installations on local vegetation.

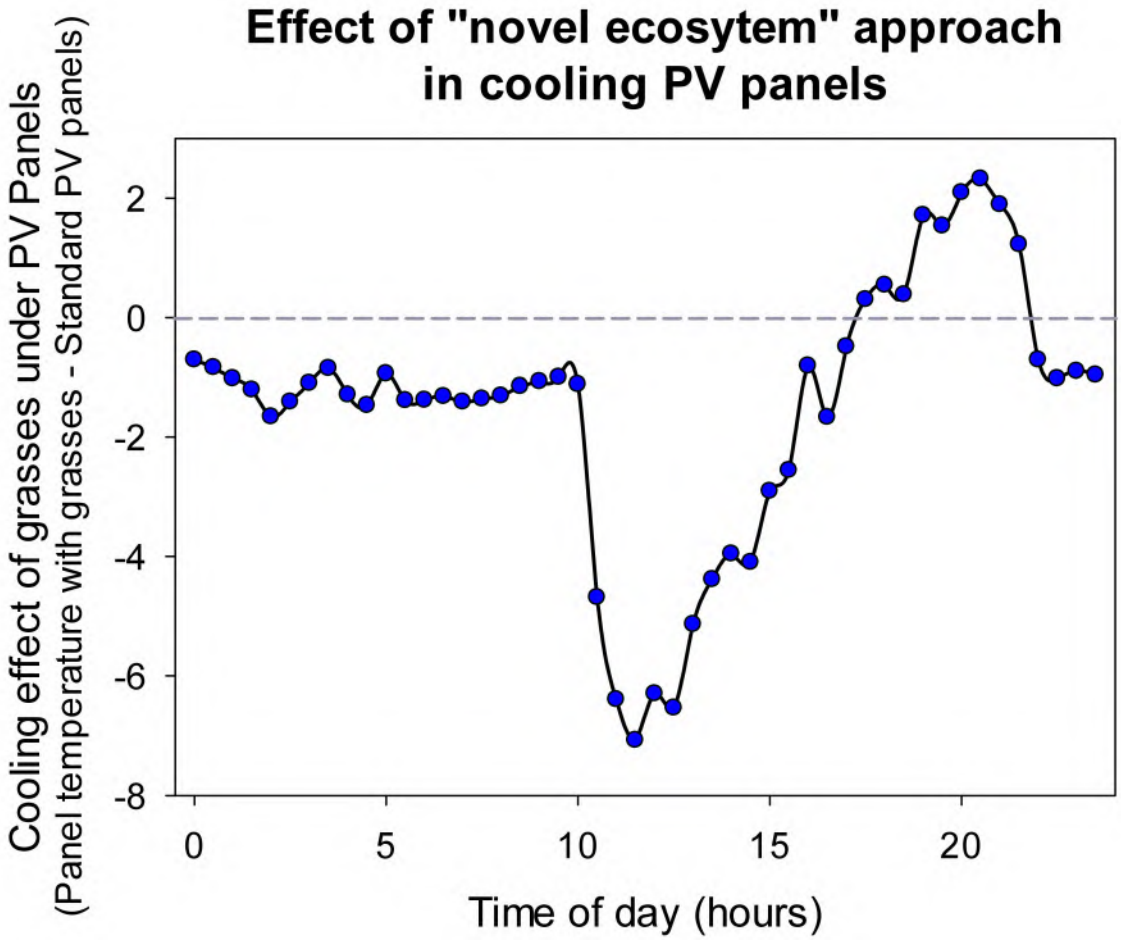

Figure 6. Measures of air temperature within a PV array restored with an understory of grasses versus a PV installation with only bare soil. The dotted line at 0 on the Y-axis illustrates when there is no difference between these measurements, and a negative value indicates the cooling effect of having a PV array restored with grasses. At night, the PVHI effect was cooled by about 1.5 ^{o}C, and the daytime PVHI effect was reduced by up to 7°C within the solar array. The reduced impacts in the early evening are likely due to the vegetation being 'shut down' for the day and, therefore, not providing any transpirational cooling.

Closer to the proposed Project site, co-location of grazing of sheep beneath an overstory of PV panels have illustrated a lack of quantifiable evidence of detrimental effects on livestock:
https://parkessolarfarm.com.au/Library/sheep-grazing-under-neoen-solar-farm/

I understand that grasses will be retained at the proposed Project site. While no published research to date measures the impacts at such a large spatial footprint, I believe that leaving the grasses under the panels should greatly reduce the PVHI effect within the solar farm, which will serve to only assist in any reductions in the spatial extent of the PVHI effect outside of the array.

Agriculture + Photovoltaics

Recently, my colleagues and I have been investigating a novel approach to co-located "green" agriculture and "grey" solar PV infrastructure, where crops are grown in the shade of the PV panels within a solar farm – a practice we call 'agrivoltaics'. We suggest that this novel energy and food generating ecosystem may become an important - but as yet under investigated - mechanism for maximizing crop yields, efficiently delivering water to plants, and generating renewable energy (Figure 7). Similar pilot studies in France and Germany have also suggested that this co-location can have beneficial effects on a balanced approach to food and renewable energy production. Beyond illustrating innovative applications in renewable energy systems, the co-location of an agriculture and PV arrays suggests that there are no ill effects of PV arrays on food production. Through our extensive measures of photosynthetic rates, transpirational water loss, and total fruit production, we have found no evidence to suggest that plants overheat or lose their potential to function by being in (extremely) close proximity to PV panels. In fact, in many cases production is increased, and water use efficiency becomes much higher because the solar panels reduced direct sunlight on the soils that drive the evaporation of irrigated waters.

Additionally, we have found that PV panels in a traditional ground-mounted array were significantly warmer in the day and experienced greater within-day variation than panels over an agrivoltaic understory, illustrating the cooling effect of vegetation. We attribute these lower daytime temperatures in PV panels in the

agrivoltaic system to the greater balance of latent heat energy exchange from plant transpiration relative to sensible heat exchange from radiation off bare soil (the typical installation method). Across the core growing season, PV panels in an agrivoltaic system were ~ 8.9+0.2^{o}C cooler in the day. These data suggest that even a vegetative barrier can significantly cool panels and the local atmosphere below those caused by the PVHI effect.

Figure 7. The co-location of agricultural under an elevated 'overstory' of PV panels has demonstrated increased production of some crop species (tomatoes, carrots, cabbages, chiltepin peppers, and kale) and increased water savings in the irrigation needed for additional spring and summer crops including red and yellow chards, purple, tepary, and cow beans, cilantro, and Japanese eggplant.

3.5 General Implications of the Above Studies and Literature for the Proposed Project

Comparative characteristics of the Arizona and Shepparton sites

Given recent work has shown that the Urban Heat Island effect is greater in locations with higher background temperatures (*Taha 2017*), it is important to consider comparative characteristics of the Arizona site, where much of my work has been conducted, and the Shepparton site under consideration here. Average climate data for Tucson (https://www.usclimatedata.com/climate/tucson/arizona/united-states/usaz0247) and Shepparton (http://www.bom.gov.au/climate/averages/tables/cw_081125.shtml) illustrate that Tucson is consistently warmer in terms of maximum and minimum temperatures in both the winter and summer seasons. Also noteworthy are vegetative differences in terms of understory vegetation. The installations in the Southwestern USA often are mechanically bladed to remove all vegetation, where as the proposed Project site will retain grasses in the understory. As noted above (Figure 6), this understory vegetation can provide significant cooling to mitigate the PVHI effect within a PV array. As such, we are working to adapt this type of practice more often here in the US installations.

Taken together with the results of *Taha 2017*, I would predict that the degree of PVHI within Shepparton might be lower than the values we measured in Tucson because of the differences in background temperatures and vegetation.

Table 1. A comparison of climatic differences between Tucson, Arizona, USA and Shepparton, Victoria, Australia, underscores the higher average temperatures of the Southwestern USA, which may lead to an elevated PVHI effect in the region.

	Summer		Winter	
	Maximum	Minimum	Maximum	Minimum
Tucson, Arizona, USA	38.1	24.7	18.9	5.5
Shepparton, Victoria, Australia	31.9	15.3	13.3	3.3

Potential for associated impact on bird and insect populations in the area

I have no experience in detecting ill effects on bird or insect populations in or around PV arrays, other than those that stem from a lack of vegetation. The fact that understory grass vegetation will be retained here should actually help to maintain local insect and bird abundances and biodiversity. Still, bolstering bird and insect populations could be achieved through either targeted revegetation efforts around the PV array or through co-location of PV and pollinator friendly vegetation, as has been carried out in multiple locations (Figure 8, for example). Multiple example stories are listed within the References section (5.2) of this report.

Beyond illustrating innovative applications in renewable energy systems, the co-location of pollinator habitat and grazing with PV arrays suggests that there are no ill effects of PV arrays on this vegetation or animals. Plants do not overheat or lose their potential to function by being in (extremely) close proximity to PV panels. Given that our research has shown that the increase in temperatures due to the PVHI effect do not extend past 30m, I do believe that off-site impacts on birds and insets are highly unlikely. Revegetating with native and locally adapted species will ensure that the solar farm does not contribute to any insect pest outbreaks that could negatively impact local agricultural areas.

Figure 8. The co-location of grasses and native or locally adapted pollinator species under an 'overstory' of PV panels has demonstrated increased abundance of bird populations and locally important pollinator species.
Photo of the Westmill Solar Park in Watchfield, England; Photo credit: Guy Parker

4 CONCLUSIONS

WILL THE PROJECT CHANGE ANY ONSITE OR OFFSITE TEMPERATURE?

In summary, both my own research and that of independent groups with which I am not affiliated have shown that solar farms can create PVHI effect, but the spatial extent of the effect is constrained. The PVHI effect is largely driven by the absence of vegetation and the vegetation's potential to cool the atmosphere through transpirational water loss. Bolstering the presence of vegetation through co-location (as described in Section 3.4) or having landscaping around the solar farm will mitigate the PVHI effect. My own research on adding grasses back into a solar farm showed the impacts of grasses on reducing the PVHI effect within a solar array. To-date, no study has published research on these patterns at such large scales, but I have no reason to believe that there will be a different outcome when extrapolated in scale. The increased practice of leaving or re-introducing vegetation within PV solar farms is acknowledging the multiple benefits that come from this practice.

Adding a vegetative buffer to the study site does not seem necessary to creating the dissipation of the PVHI effect as one moves outside of the PV array, as neither of the studies I have conducted or those described by *Fthenakis and Yu (2013)* monitored solar farms with a vegetative buffer.

I have made all of the enquiries that I believe are desirable and appropriate and that no matters of significance which I regard as relevant have to my knowledge, been withheld from the Panel.

Greg Barron-Gafford, PhD
University of Arizona
3 May 2018

5 REFERENCES

5.1 REFERENCES FOR PEER-REVIEWED MANUSCRIPTS CITED WITHIN THIS REPORT

Barron-Gafford, G. A. *et al.* The Solar Heat Island Effect: Larger solar power plants increase local temperatures. *Nature Scientific Reports* **6: 35070**, DOI: 10.1038/srep35070 (2016).

Fthenakis, V. & Yu, Y. Analysis of the potential for a heat island effect in large solar farms. *Analysis of the potential for a heat island effect in large solar farms; 2013 IEEE 39th Photovoltaic Specialists Conference*, 3362-3366 (2013).

Rajagopalan, P., Lim, K. C. & Jamei, E. Urban heat island and wind flow characteristics of a tropical city. Solar Energy 107, 159-170, doi:10.1016/j.solener.2014.05.042 (2014).

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Yang, L. *et al.* Study on the local climatic effects of large photovoltaic solar farms in desert areas. *Solar Energy* **144**, 244-253, doi:10.1016/j.solener.2017.01.015 (2017).

5.2 REFERENCES FOR IMPACT ON BIRD AND INSECT POPULATIONS IN PV SOLAR FARMS

https://www.solarpowerworldonline.com/2017/05/pollinator-friendly-solar-vegetation/

http://eanvt.org/wp-content/uploads/2017/04/The-Effects-of-Solar-Farms-on-Local-Biodiversity-A-Comparative-Study-UK.pdf

https://www.greenbiz.com/article/pollinator-friendly-solar-sites

http://agriculture.vermont.gov/node/1507

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CHRONOLOGY OF EDUCATION

2005-2010 University of Arizona, Tucson, Arizona, USA
Ph.D. Ecology & Evolutionary Biology, 2010
Dissertation: *Temperature and precipitation controls over soil, leaf and ecosystem level CO_2 flux along a woody plant encroachment gradient*
Advisor: Travis Huxman

1998-2001 University of Georgia, Athens, Georgia, USA
M.S. Forest Ecology, 2001
Thesis: *The effects of increasing stand density on nutrient limitations to growth and nutrient budgets multi-species pine stands*
Advisors: Robert Teskey and Rodney Will

1994-1998 Texas Christian University, Ft. Worth, Texas, USA
B.S. Environmental Science, 1998
Thesis: *Analysis of forest structure and function at Huntsville State Park, Texas*
Advisors: Leo Newland and Glenn Kroh

CHRONOLOGY OF EMPLOYMENT

Aug 2017 – Present: **Tenure Track Associate Professor**, School of Geography & Development, University of Arizona, Tucson, AZ, 85721

Aug 2016 – Present: **Associate Director**, School of Geography & Development, University of Arizona, Tucson, AZ, 85721

Aug 2013 – Present: **Tenure Track Assistant Professor**, School of Geography & Development, University of Arizona, Tucson, AZ, 85721

Aug 2013 – Present: **Tenure Track Assistant Professor**, Biosphere 2, College of Science, University of Arizona, Tucson, AZ, 85721

Feb 2010 – Aug 2013: **Assistant Research Professor** and **Associate Research Scientist**, Biosphere 2, College of Science, University of Arizona, Tucson, AZ, 85721

Feb 2010 – Aug 2010: **Postdoctoral Research Associate**, Department of Botany, University of Wyoming, Laramie, WY, 82071

Dec 2003 – Feb 2010: **Research Specialist**, Department of Ecology & Evolutionary Biology, University of Arizona, Tucson, AZ, 85721

June 2001 – Dec 2003: **Senior Research Specialist**, Lamont-Doherty Earth Observatory ~ Biosphere 2, Columbia University, Palisades, NY, 10964

SERVICE / OUTREACH

Local / state outreach

2017	University of Arizona Museum of Art ~ *Art-Science Connections*
2017 – Present	Tucson Unified School District ~ *Rincon/University High Schools & Manzo Elementary School: Agrivoltaics installation and curriculum development*
2017	University of Arizona Biosphere 2 ~ *Earth Day: Agrivoltaics Hands-on Experiential learning station*
2017	University of Arizona Biosphere 2 ~ *Science Saturday: Agrivoltaics Presentations and Hands-on Experiential learning station*
2016	University of Arizona Museum of Art ~ *Fires of Change Panelist*
2013	Tumamoc Hill Public Lecture Series ~ *Lectures in the Libraries*
2013	The Santa Rita Experimental Range ~ *Discovery Saturday Public Series*
2008 – 2014	Science Saturdays (Hands-on Science activities) at Biosphere 2
2008 – Present	Informal presentations with Biosphere 2 visitors as we conduct experiments along the tour route

National / Professional

2017 – Present	Onsite Reviewer ~ U.S. National Science Foundation Environmental Biology
2017 – Present	Virtual Panel Reviewer ~ Swiss National Science Foundation, Swiss National Science Foundation Professorship
2017 – Present	Virtual Panel Reviewer ~ Israeli Science Foundation, China-Israel Research Program (CIRP) Review Panel
2017 – Present	International External Reviewer ~ University of Adelaide (Australia), External reviewer for doctoral dissertation
2017 – Present	International External Reviewer ~ Edith Cowan University (Australia), External reviewer for doctoral dissertation
2016 – Present	Onsite Reviewer ~ U.S. National Science Foundation Ecosystem Science Cluster program Doctoral Dissertation Improvement Grants (DDIG)
2013 – Present	Onsite Reviewer ~ U.S. Environmental Protection Agency (EPA) Science to Achieve Results (STAR) Graduate Fellowship

National / Professional (continued)

2013 – Present	Section Editor ~ *Annual Reviews in Plant Biology*
2013 – Present	Session Organizer for the Annual Meeting of the American Geophysical Union
2012 – Present	Section Editor ~ *Physiological Ecology of Photosynthesis* within *Oxford Bibliographies in Ecology*
2010 – Present	Oral presentation and poster judge for graduate student awards at the Annual Meeting of the American Geophysical Union
2010 – Present	Oral presentation and poster judge for Ecological Society of America's Plant Physiological Ecology section awards

2002 – Present	Journal Reviewer. (2012– 11; 2013- 12; 2014- 8; 2015- 9; 2016 – 8 so far): Representative Journals: *Journal of Biogeography, Agricultural and Forest Meteorology, Global Change Biology, Journal of Arid Environments, Nature, Nature Scientific Reports, Nature Energy, Journal of Geophysical Research-Atmospheres, Journal of Geophysical Research-Biogeosciences, New Phytologist, Methods in Ecology & Evolution, Oecologia*

University

2016 – 2017	Ecosystem Genomics Cluster Hire, Earth Sciences executive hiring committee
2015 – Present	UA Arid lands Steering Committee
2015 – Present	Art-Environment Network Governance Committee Member, Institute of the Environment
2014	University of Arizona Foundation Expo of Excellence, representing the School of Geography& Development and Biosphere 2's partnership in STEAM education programming with Manzo Elementary
2014	Water, Environmental, and Energy Solutions (WEES) Faculty Proposal Review Board
2013 – Present	National Ecological Observatory Network Regional Site Selection Committee
2013 – Present	UofA Sky School, Mt. Lemmon Sky Center – Project Organizer
2012 – Present	Institute of the Environment Faculty Exploratory Grant Referee
2011 – Present	University Representative for the Consortium of Universities Allied for Water Research (NSF sponsored program)
2011 – Present	Institute of the Environment Graduate Award Reviewer

Department

2016 – Present	SGD Associate Director
2014 – Present	SGD Undergraduate Committee
2014 – Present	SGD Curriculum and Assessment Committee

Department (continued)

2013 – 2015	SGD Graduate Committee
2013 – Present	Physical Geography Curriculum Sub-committee
2013 – Present	UC-San Diego Academic Connections, in partnership with Biosphere 2 – Project Organizer & student mentor
2013 – 2014	Association of Pacific Coast Geographers Conference Planning Committee
2013 – 2015	Biosphere 2 Earth Month Programming
2013 – 2015	Arizona Center for STEM Teachers – Presenter for weeklong program
2013 – 2014	Physical Geographer Position Hiring Committee
2010 – 2014	Advisor for Biosphere 2 Research Technicians
2011 – Present	Critical Zone Observatory – Ecohydrological Partitioning Sub-committee
2010 – Present	Specialty Tour Guide for Biosphere 2 VIP visitors

Societies

2014 – Present	Association of Pacific Coast Geographers (APCG)
2013 – Present	American Association of Geographers (AAG)
2007 – Present	American Geophysical Union (AGU)
2003 – Present	Ecological Society of America (ESA)

PUBLICATIONS / CREATIVE ACITIVITY

H-index (ISI)……22
Citations (ISI, October, 2017)……1635
Articles published in peer review journals……63
Articles in review……6
Other peer reviewed articles and book chapters……3

Chapters in scholarly books

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1. **Barron-Gafford GA (2015).** *Physiological Ecology of Photosynthesis*. Oxford Bibliographies Online Resource Library. DOI: 10.1093/OBO/9780199830060-0093

Conference Proceedings

3. **Barron-Gafford GA**, Osmond CB, Grieve KA, Lipson D, and Murthy R. (2005) Elevated CO_2 differentially effects photosynthesis and carbon balance in poplar stands, a four year study. In: van der Est, A. and Bruce, D. (eds). *Photosynthesis: Fundamental Aspects to Global Perspectives: Proceedings 13th International Congress on Photosynthesis*. ACG Publishing (Photosynthesis and Global Change, 973-976).

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1. Will RE, **Barron GA**, Teskey RO, and Shiver B. (2005). Within and between canopy variability of foliar nitrogen concentrations for loblolly and slash pine stands planted at different densities. *Biennial Southern Silviculture Conference Proceedings*.

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63. **Barron-Gafford GA**, Sanchez-Cañete EP, Hendryx S, Minor RL, Colella T, Murphy P, Lee E, Scott RL, Kumar P. (2017). Impacts of hydraulic redistribution on grass-tree competition versus facilitation in a semiarid savanna. *New Phytologist*, **215**: 1451-1461.

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60. Sanchez-Canete EP, Scott RL, van Haren J, **Barron-Gafford GA**. (2017). Improving the accuracy of the gradient method for determining soil carbon dioxide efflux. *Journal of Geophysical Research-Biogeosciences*, **122**: 50-64.

59. van Haren J, Dontsova K, **Barron-Gafford GA**, Troch PA, Chorover J, Delong SB, Breshears DD, Huxman TE, Pelletier JD, Saleska SR, et al. (2017). CO_2 diffusion into pore spaces limits weathering rate of an experimental basalt landscape. *Geology*, **45**: 203-206.

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56. Scott RL, Biederman JA, Hamerlynck EP, **Barron-Gafford GA**. (2015). The carbon balance pivot point of southwestern U.S. semiarid ecosystems: Insights from the 21st century drought. *Journal of Geophysical Research-Biogeosciences*, **120**: 2612-2624, doi: 10.1002/2015JG003181.

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46. Nelson K, Kurc SA, John G, Minor RL, **Barron-Gafford GA**. (2014). Influence of snow cover duration on soil evaporation and respiration efflux in mixed- conifer ecosystems. *Ecohydrology*, **7**: 869-880.

45. Kimball S, Gremer JR, **Barron-Gafford GA**, Angert AL, Huxman TE, Venable DL. (2014). High water-use efficiency and growth contribute to success of non-native *Erodium cicutarium* in a Sonoran Desert winter annual community. *Conservation Physiology*, **2**: cou006, doi:10.1093/conphys/cou006.

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3. **Barron-Gafford GA**, RE Will, EC Burkes, B Shiver, Teskey RO. (2003). *Nutrient concentrations and contents, and their relation to stem growth, of intensively managed *Pinus taeda* and *Pinus elliottii* stands of different planting densities. *Forest Science*, **49**: 291-300.

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1. Will, RE, **Barron GA**, Burkes EC, Shiver BD, Teskey RO. (2001). *Relationship between intercepted radiation, net photosynthesis, respiration, and rate of stem volume growth of *Pinus taeda* and *Pinus elliottii* stands of different densities. *Forest Ecology and Management*, **154**: 155-163.

WORK IN PROGRESS

Articles in peer review, final preparation, or revision

6. Adams HA, **Barron-Gafford GA**, Minor RL, Gardea AA, Bentley LP, Breshears DD, Dowell NG, Huxman TE. (*In Re-review post-revision*). Ever increasing drought-induced mortality risk for tree species with ever rising temperatures. *Environmental Research Letters.*

5. Elshall AS, Ye M, Niu G-Y, **Barron-Gafford GA**. (*In Re-review post-revision*). Impacts of Residual Models on Bayesian Inference and Predictive Performance of Soil Respiration Models. *Journal of Geophysical Research – Biogeosciences*.

4. Elshall AS, Ye M, Niu G-Y, **Barron-Gafford GA**. (*In Re-review post-revision*). Relative Model Score: A Multi-Criteria Metric for Measuring Relative Predictive Performance of Multiple Models. *Water Resources Research*.

3. Lee E, Kumar P, **Barron-Gafford GA**, Hendryx S, Sanchez-Cañete EP, Minor RL, Colella T, Scott RL. (*In Review*). Impact of hydraulic redistribution on multispecies vegetation water use in a semi-arid savanna ecosystem: An experimental and modeling synthesis. *Water Resources Research*.

2. Froend RH, Breshears DD, Law DJ, **Barron-Gafford GA**. (*In Review*). Phreatophytes in the Anthropocene: State and Transition Models for Climate Change and Land Use Pressures. *Earth's Future*.

1. Minor J, Colella TR, Barnes M, Mann S, Murphy P, Pearl J, **Barron-Gafford GA**. (*In Review*). Critical Zone Science in the Anthropocene: Opportunities for Biogeographic Theory and Praxis to Drive Earth Science Integration. *Global Ecology and Biogeography*.

MEDIA OUTREACH

2017 UA News. *UA Researchers Plant Seeds to Make Renewable Energy More Efficient.* Interviewee discussing Agrivoltaics as an experiment in combining agriculture with energy efficiency, involves growing plants beneath solar panels, community outreach with Manzo Elementary and University High School, and the linkage between School of Geography & Development and Biosphere 2. Full online version: https://uanews.arizona.edu/story/ua-researchers-plant-seeds-make-renewable-energy-more-efficient?utm_source=uanow&utm_medium=email&utm_campaign

2016 ResearchGate. *Solar energy is hot right now, in more ways than one.* Interviewee discussing unintended impacts of large-scale renewable energy through photovoltaics. Full online version: https://www.researchgate.net/blog/post/solar-energy-is-hot-right-now-in-more-ways-than-one

2016 Arizona Daily Star. *Critical Zone Observatory gets grant to extend research.* Interviewee discussing the inter- and cross-disciplinary research within the context of the Critical Zone Observatory, and the linkage between School of Geography & Development and Biosphere 2. Full online version: http://tucson.com/news/science/environment/critical-zone-observatory-gets-grant-to-extend-research/article_aa4df9dc-a7a1-11e6-9f60-b341da1029a7.html

2014 Bill Buckmaster Show. *Superstars of Science.* Interviewee discussing the Manzo Elementary project, STEAM learning (including Art in STEM education), and the linkage between School of Geography & Development and Biosphere 2. Full online version: http://www.buckmastershow.com/2014/04/24/buckmaster-show-4242014-tusd-struggles-to-keep-students/

2013 Tucson Weekly (cover story). *Learning through Landscapes*. Interviewee on the partnership between School of Geography & Development and Biosphere

2 with Manzo Elementary to introduce a new STEM learning program. Full online version: http://www.tucsonweekly.com/tucson/learning-through-landscapes/Content?oid=3918303

2013 Arizona Public Media. Interviewee on the biogeography of woody plant expansion and the linkage between School of Geography & Development and Biosphere 2. https://ondemand.azpm.org/videoshorts/watch/2013/9/16/26865-grassland-faces-threats-from-mesquite-trees-woody-plants/

CONFERENCES AND SCHOLARLY PRESENTATIONS *(limited to period in rank)*

Invited Symposia (limited to period in rank)

Barron-Gafford GA (*Invited speaker*). Biogeography in the Critical Zone: Insights from the Mountain Tops and Valley Floor. UCLA Department of Geography Tod Spieker Colloquium Series. Tucson, Arizona. November, 2015.

Barron-Gafford GA (*Invited speaker*). Ecohydrology in our Critical Zone: Insights from Semiarid Mountain Tops to the Valley Floor. School of Natural Resources & the Environment (SNRE) Colloquium. Tucson, Arizona. October, 2015.

Barron-Gafford GA (*Invited speaker*). Sensor Technologies and Unmanned Aerial Vehicles (drones) to Measure Ecosystem Processes in Semi-arid Environments. Research Insights in Semiarid Ecosystems (RISE) Symposium. Tucson, Arizona. October, 2015.

Barron-Gafford GA (*Invited speaker*). Examining ecosystem function in space and time within the critical zone through the lenses of ecology and biogeography. Department of Ecology & Evolutionary Biology Colloquium. Tucson, Arizona. September, 2015.

Barron-Gafford GA (*Invited speaker*). Woody plant encroachment: Influence of landscape change on aboveground-belowground linkages, pulse dynamics, and ecosystem function. Soil, Water, & Environmental Science (SWES) Colloquium. Tucson, Arizona. November, 2013.

Barron-Gafford GA (*Invited speaker*). Exploring the ecology of semiarid land-cover and land-use change in anticipation of a changing climate. Department of Ecology & Evolutionary Biology Colloquium. Tucson, Arizona. March, 2013.

Invited conferences (limited to period in rank)

Barron-Gafford GA. Lags and Legacies in Ecosystem Processes: Challenges and Opportunities for Biogeographers and Ecologists. Frontiers in Experimental Ecosystem Science. Paris, France. July, 2015.

Scott RL, Huxman TE, **Barron-Gafford GA**, Jenerette GD, Young JM. The ecohydrological consequences of woody plant encroachment: How accessibility to deep soil water Resources affects ecosystem carbon and water exchange (*Invited*). American Geophysical Union's Annual Fall Meeting, Dec. 9-13, 2013, San Francisco, CA.

Submitted presentations (limited to period in rank)

Barron-Gafford GA, Allen N, Minor RL, Pavao-Zuckerman M. The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Scott RL, **Barron-Gafford GA**, Biederman JA. Insights from a network of long-term measurements of biosphere-atmospheric exchanges of water vapor and carbon dioxide in southern Arizona. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Barron-Gafford GA, Minor RL, Hendryx, S, Lee E, Sutter L, Colella T, Murphy P, Sanchez-Cañete EP, Hamerlynck EP, Kumar P, Scott RL. Impacts of hydraulic redistribution on overstory-understory interactions in a semiarid savanna. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Sanchez-Cañete EP, Scott RL, Van Haren JLM, **Barron-Gafford GA**. The Necessity of Determining the Gas Transfer Coefficient In-situ to Obtain More Accurate Soil Carbon Dioxide Effluxes Through the Gradient Method. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Elshall AS, Ye M, Niu G-Y, **Barron-Gafford GA**. Numerical Demons in Monte Carlo Estimation of Bayesian Model Evidence with Application to Soil Respiration Models. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Murphy P, Minor RL, Sanchez-Cañete EP, Potts DL, **Barron-Gafford GA**. Seasonal and Topographic Variation in Net Primary Productivity and Water Use Efficiency in a Southwest Sky Island Forest. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Lee E, Kumar P, , **Barron-Gafford GA**, Scott RL. An Experimental and Modeling Synthesis to Determine Seasonality of Hydraulic Redistribution in Semi-arid Region with Multispecies Vegetation Interaction. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Sutter L, Sanchez-Cañete EP, **Barron-Gafford GA**. Aspect as a Driver of Soil Carbon and Water Fluxes in Desert Environments. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Hingley R, Juarez S, Dontsova K, Hunt E, Le Galliard J-F, Chollet S, Cros A, Llavata M, Massol F, Barré P, Gelabert A, Daval D, Troch PA, **Barron-Gafford GA**, Van Haren JLM, Ferrière R. Effects of Climate Change and Vegetation Type on Carbon and Nitrogen Accumulation during Incipient Soil Formation. American Geophysical Union's Annual Fall Meeting, Dec. 12-16, 2016, San Francisco, CA.

Sanchez-Cañete EP, **Barron-Gafford GA**, van Haren J, Scott RL. Accurate long-term soil respiration fluxes based on the gradient method in a semiarid ecosystem. University of Arizona Arid Lands Poster Session, April, 2016, Tucson, AZ.

Murphy P, Minor RL, Potts DL, **Barron-Gafford GA**. Studying Topographic Controls on Primary Productivity. University of Arizona Arid Lands Poster Session, April, 2016, Tucson, AZ.

Sutter L, Sanchez-Cañete EP, **Barron-Gafford GA**. An important aspect of soil carbon and water fluxes in desert environments. University of Arizona Arid Lands Poster Session, April, 2016, Tucson, AZ.

Hendryx S, Minor RL, Colella T, Murphy P, Lee E, Scott RL, Kumar P, **Barron-Gafford GA**. Impacts of hydraulic redistribution on plant and soil carbon and water fluxes in a dryland savanna. University of Arizona Arid Lands Poster Session, April, 2016, Tucson, AZ.

Colella T, Mann SN, Murphy P, Minor J, Pearl J, Barnes M, Gallery R, Swetnam T, **Barron-Gafford GA**. Critical Zone Science in the Anthropocene. Association of American Geographers Annual Meeting, April, 2016, San Francisco, CA.

Elshall AS Ye M, Niu G-Y, **Barron-Gafford GA**. Bayesian multimodel inference of soil microbial respiration models: Theory, application and future prospective. American Geophysical Union's Annual Fall Meeting, Dec. 14-18, 2014, San Francisco, CA.

Scott RL, Biederman J, **Barron-Gafford GA**, Hamerlynck EP. The Carbon Balance Pivot Point of Southwestern U.S. Semiarid Ecosystems: Insights From the 21st Century Drought. American Geophysical Union's Annual Fall Meeting, Dec. 14-18, 2014, San Francisco, CA.

Barron-Gafford GA, Minor RL, Heard MM, Sutter LF, Yang J, Potts DL. Complex terrain in the Critical Zone: How topography drives ecohydrological patterns of soil and plant carbon exchange in a semiarid mountainous system. American Geophysical Union's Annual Fall Meeting, Dec. 14-18, 2014, San Francisco, CA.

Lee E, Kumar P, **Barron-Gafford GA**, Scott RL, Hendryx S, Sanchez-Cañete EP. Determining the Role of Hydraulic Redistribution Regimes in the Critical Zone. American Geophysical Union's Annual Fall Meeting, Dec. 14-18, 2014, San Francisco, CA.

Sanchez-Cañete EP, **Barron-Gafford GA**, van Haren JLM, Scott RL. Improving soil CO2 efflux estimates from in-situ soil CO2 sensors with gas transport measurements. American Geophysical Union's Annual Fall Meeting, Dec. 14-18, 2014, San Francisco, CA.

Parra EA, McFarland E, Minor RL, Heard MM, **Barron-Gafford GA**. Effects of isoprene production on the photosynthetic performance of Poplars (*Populus* sp.) under thermal and moisture stress. American Geophysical Union's Annual Fall Meeting, Dec. 14-18, 2014, San Francisco, CA.

Barron-Gafford GA. Examining ecosystem function in space and time within the critical zone through the lenses of ecology and biogeography. Ecological Society of America's Annual Meeting, August, 2015, Baltimore, MD.

Barron-Gafford GA. Capturing heterogeneity in carbon fluxes in space and time across a semiarid montane forest. Association of American Geographers Annual Meeting, April, 2015, Chicago, IL.

Elshall AS, Ye M, **Barron-Gafford GA**. Quantification of Model Uncertainty in Modeling Mechanisms of Soil Microbial Respiration Pulses to Simulate Birch Effect. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Pfeiffer AW, Minor RL, Heard MM, **Barron-Gafford GA**. Photosynthetic response of Poplars (*Populus*) to climatic stressors: Investigating isoprene's role in increasing tolerance to temperature and atmospheric water stress in Arizona. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Ibsen P, Van Leeuwn WJD McCorkel J, **Barron-Gafford GA**, Moore DJ. Physiology and thermal imaging of Poplar hybrids with varying temperature tolerance. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Troch PA, **Barron-Gafford GA**, Dontsova K, Fang Y, Niu G-Y, Pangle LA, Tuller M, Van Haren JLM. Monitoring and modeling water, energy and carbon fluxes at the hillslope scale in the Landscape Evolution Observatory. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Scott RL, Biederman JA, **Barron-Gafford GA**. The coupling of ecosystem productivity and water availability in dryland regions. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Ruiz J, Van Haren JLM, Dontsova K, **Barron-Gafford GA**, Troch PA, Chorover J. Rapid CO_2 consumption during incipient weathering of a granular basaltic hillslope in the Landscape Evolution Observatory, Biosphere 2. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Pavao-Zuckerman M, Knerl A, **Barron-Gafford GA**. Ecohydrology frameworks for green infrastructure design and ecosystem service provision. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Pfeiffer AW, Minor RL, Heard MM, **Barron-Gafford GA**. Photosynthetic response of Poplars (*Populus*) to climatic stressors. American Geophysical Union's Annual Fall Meeting, Dec. 15-19, 2014, San Francisco, CA.

Barron-Gafford GA, Minor RL, Heard M, Barrows J, Allen N. Using Water Smart Design and an Ecosystem Services Approach to Fight Solar Heat Islanding and Enhance Renewable Energy Production. Association of Pacific Coast Geographers Annual Meeting, Sept. 24-27, 2014, Tucson, AZ.

Barron-Gafford GA, Minor RL, Heard M, Yang J, Wright C, Potts DL. Aspect as a source of heterogeneity in carbon & water fluxes in space and time. National Critical Zone Observatory All-Hands Meeting, Sept. 21-24, 2014, Yosemite, CA.

Chorover J, Pelletier J, Breshears DD, McIntosh J, Rasmussen C, Brooks P, **Barron-Gafford GA**, Gallery R, Ferré T, Litvak M, Meixner T, Niu G-Y, Papuga S, Rich V, Schaap M, Troch P. The Catalina-Jemez CZO: Transformative Behavior of Energy, Water and Carbon in the Critical Zone II. Interactions between Long and Short Term Processes that Control Delivery of Critical Zone Services. National Critical Zone Observatory All-Hands Meeting, Sept. 21-24, 2014, Yosemite, CA.

Barron-Gafford GA. Heat islanding around solar energy installations ~ Valid concern or unnecessary worry about renewable energy production. Association of American Geographers Annual Meeting, April 8-12, 2014, Tampa, FL.

Barron-Gafford GA, Minor RL, van Haren J, Dontsova K, Troch PA. Precipitation pulse dynamics of carbon sequestration and efflux in highly weatherable soils. American Geophysical Union's Annual Fall Meeting, Dec. 9-13, 2013, San Francisco, CA.

Niu G, Zhang X, **Barron-Gafford GA**, Pavao-Zuckerman M. Modeling the "Birch Effect" using a microbial enzyme based soil organic carbon decomposition and gas transport model. American Geophysical Union's Annual Fall Meeting, Dec. 9-13, 2013, San Francisco, CA.

Yang J, **Barron-Gafford GA**, Minor RL, Heard M. Examining the physical drivers of photosynthetic temperature sensitivity within a sub-alpine mixed conifer forest. American Geophysical Union's Annual Fall Meeting, Dec. 9-13, 2013, San Francisco, CA.

van Haren J, **Barron-Gafford GA**, Dontsova K. CO_2 sequestration through weathering of basalt tephra in the Landscape Evolution Observatory (LEO). American Geophysical Union's Annual Fall Meeting, Dec. 9-13, 2013, San Francisco, CA.

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Community Presentations (limited to period in rank)

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Barron-Gafford GA. "Experiential Ecological Learning as a Transformative Gateway in Elementary Learning". Arizona Center for STEM Teachers (ACST) Residential Teacher Training Workshop at Biosphere 2, Tucson, AZ. July, 2013.

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The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures

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While photovoltaic (PV) renewable energy production has surged, concerns remain about whether or not PV power plants induce a "heat island" (PVHI) effect, much like the increase in ambient temperatures relative to wildlands generates an Urban Heat Island effect in cities. Transitions to PV plants alter the way that incoming energy is reflected back to the atmosphere or absorbed, stored, and reradiated because PV plants change the albedo, vegetation, and structure of the terrain. Prior work on the PVHI has been mostly theoretical or based upon simulated models. Furthermore, past empirical work has been limited in scope to a single biome. Because there are still large uncertainties surrounding the potential for a PHVI effect, we examined the PVHI empirically with experiments that spanned three biomes. We found temperatures over a PV plant were regularly 3–4 °C warmer than wildlands at night, which is in direct contrast to other studies based on models that suggested that PV systems should decrease ambient temperatures. Deducing the underlying cause and scale of the PVHI effect and identifying mitigation strategies are key in supporting decision-making regarding PV development, particularly in semiarid landscapes, which are among the most likely for large-scale PV installations.

Electricity production from large-scale photovoltaic (PV) installations has increased exponentially in recent decades[1–3]. This proliferation in renewable energy portfolios and PV powerplants demonstrate an increase in the acceptance and cost-effectiveness of this technology[4,5]. Corresponding with this upsurge in installation has been an increase in the assessment of the impacts of utility-scale PV[4,6–8], including those on the efficacy of PV to offset energy needs[9,10]. A growing concern that remains understudied is whether or not PV installations cause a "heat island" (PVHI) effect that warms surrounding areas, thereby potentially influencing wildlife habitat, ecosystem function in wildlands, and human health and even home values in residential areas[11]. As with the Urban Heat Island (UHI) effect, large PV power plants induce a landscape change that reduces albedo so that the modified landscape is darker and, therefore, less reflective. Lowering the terrestrial albedo from ~20% in natural deserts[12] to ~5% over PV panels[13] alters the energy balance of absorption, storage, and release of short- and longwave radiation[14,15]. However, several differences between the UHI and potential PVHI effects confound a simple comparison and produce competing hypotheses about whether or not large-scale PV installations will create a heat island effect. These include: (*i*) PV installations shade a portion of the ground and therefore could reduce heat absorption in surface soils[16], (*ii*) PV panels are thin and have little heat capacity per unit area but PV modules emit thermal radiation both up and down, and this is particularly significant during the day when PV modules are often 20 °C warmer than ambient temperatures, (*iii*) vegetation is usually removed from PV power plants, reducing the amount of cooling due to transpiration[14], (*iv*) electric power removes energy from PV power plants, and (*v*) PV panels reflect and absorb upwelling longwave radiation, and thus can prevent the soil from cooling as much as it might under a dark sky at night.

Public concerns over a PVHI effect have, in some cases, led to resistance to large-scale solar development. By some estimates, nearly half of recently proposed energy projects have been delayed or abandoned due to local opposition[11]. Yet, there is a remarkable lack of data as to whether or not the PVHI effect is real or simply an issue

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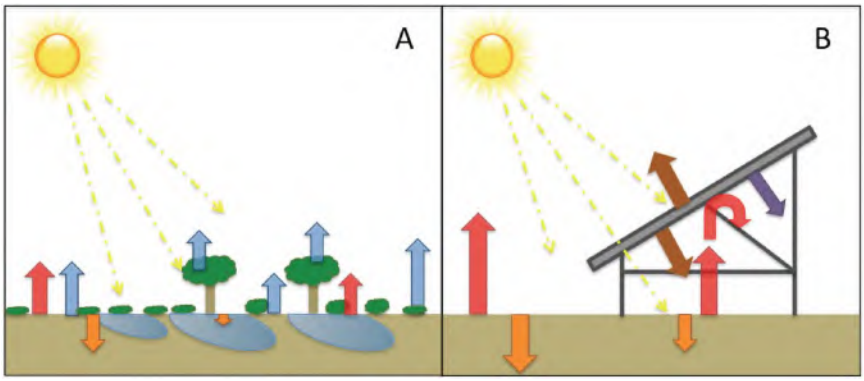

Figure 1. Illustration of midday energy exchange. Assuming equal rates of incoming energy from the sun, a transition from (**A**) a vegetated ecosystem to (**B**) a photovoltaic (PV) power plant installation will significantly alter the energy flux dynamics of the area. Within natural ecosystems, vegetation reduces heat capture and storage in soils (orange arrows), and infiltrated water and vegetation release heat-dissipating latent energy fluxes in the transition of water-to-water vapor to the atmosphere through evapotranspiration (blue arrows). These latent heat fluxes are dramatically reduced in typical PV installations, leading to greater sensible heat fluxes (red arrows). Energy re-radiation from PV panels (brown arrow) and energy transferred to electricity (purple arrow) are also shown.

associated with perceptions of environmental change caused by the installations that lead to "not in my backyard" (NIMBY) thinking. Some models have suggested that PV systems can actually cause a cooling effect on the local environment, depending on the efficiency and placement of the PV panels[17,18]. But these studies are limited in their applicability when evaluating large-scale PV installations because they consider changes in albedo and energy exchange within an urban environment (rather than a natural ecosystem) or in European locations that are not representative of semiarid energy dynamics where large-scale PV installations are concentrated[10,19]. Most previous research, then, is based on untested theory and numerical modeling. Therefore, the potential for a PHVI effect must be examined with empirical data obtained through rigorous experimental terms.

The significance of a PVHI effect depends on energy balance. Incoming solar energy typically is either reflected back to the atmosphere or absorbed, stored, and later re-radiated in the form of latent or sensible heat (Fig. 1)[20,21]. Within natural ecosystems, vegetation reduces heat gain and storage in soils by creating surface shading, though the degree of shading varies among plant types[22]. Energy absorbed by vegetation and surface soils can be released as latent heat in the transition of liquid water to water vapor to the atmosphere through evapotranspiration – the combined water loss from soils (evaporation) and vegetation (transpiration). This heat-dissipating latent energy exchange is dramatically reduced in a typical PV installation (Fig. 1 transition from A-to-B), potentially leading to greater heat absorption by soils in PV installations. This increased absorption, in turn, could increase soil temperatures and lead to greater sensible heat efflux from the soil in the form of radiation and convection. Additionally, PV panel surfaces absorb more solar insolation due to a decreased albedo[13,23,24]. PV panels will re-radiate most of this energy as longwave sensible heat and convert a lesser amount (~20%) of this energy into usable electricity. PV panels also allow some light energy to pass, which, again, in unvegetated soils will lead to greater heat absorption. This increased absorption could lead to greater sensible heat efflux from the soil that may be trapped under the PV panels. A PVHI effect would be the result of a detectable increase in sensible heat flux (atmospheric warming) resulting from an alteration in the balance of incoming and outgoing energy fluxes due to landscape transformation. Developing a full thermal model is challenging[17,18,25], and there are large uncertainties surrounding multiple terms including variations in albedo, cloud cover, seasonality in advection, and panel efficiency, which itself is dynamic and impacted by the local environment. These uncertainties are compounded by the lack of empirical data.

We addressed the paucity of direct quantification of a PVHI effect by simultaneously monitoring three sites that represent a natural desert ecosystem, the traditional built environment (parking lot surrounded by commercial buildings), and a PV power plant. We define a PVHI effect as the difference in ambient air temperature between the PV power plant and the desert landscape. Similarly, UHI is defined as the difference in temperature between the built environment and the desert. We reduced confounding effects of variability in local incoming energy, temperature, and precipitation by utilizing sites contained within a 1 km area.

At each site, we monitored air temperature continuously for over one year using aspirated temperature probes 2.5 m above the soil surface. Average annual temperature was 22.7 + 0.5 °C in the PV installation, while the nearby desert ecosystem was only 20.3 + 0.5 °C, indicating a PVHI effect. Temperature differences between areas varied significantly depending on time of day and month of the year (Fig. 2), but the PV installation was always greater than or equal in temperature to other sites. As is the case with the UHI effect in dryland regions, the PVHI effect delayed the cooling of ambient temperatures in the evening, yielding the most significant difference in overnight temperatures across all seasons. Annual average midnight temperatures were 19.3 + 0.6 °C in the PV installation, while the nearby desert ecosystem was only 15.8 + 0.6 °C. This PVHI effect was more significant in terms of actual degrees of warming (+3.5 °C) in warm months (Spring and Summer; Fig. 3, right).

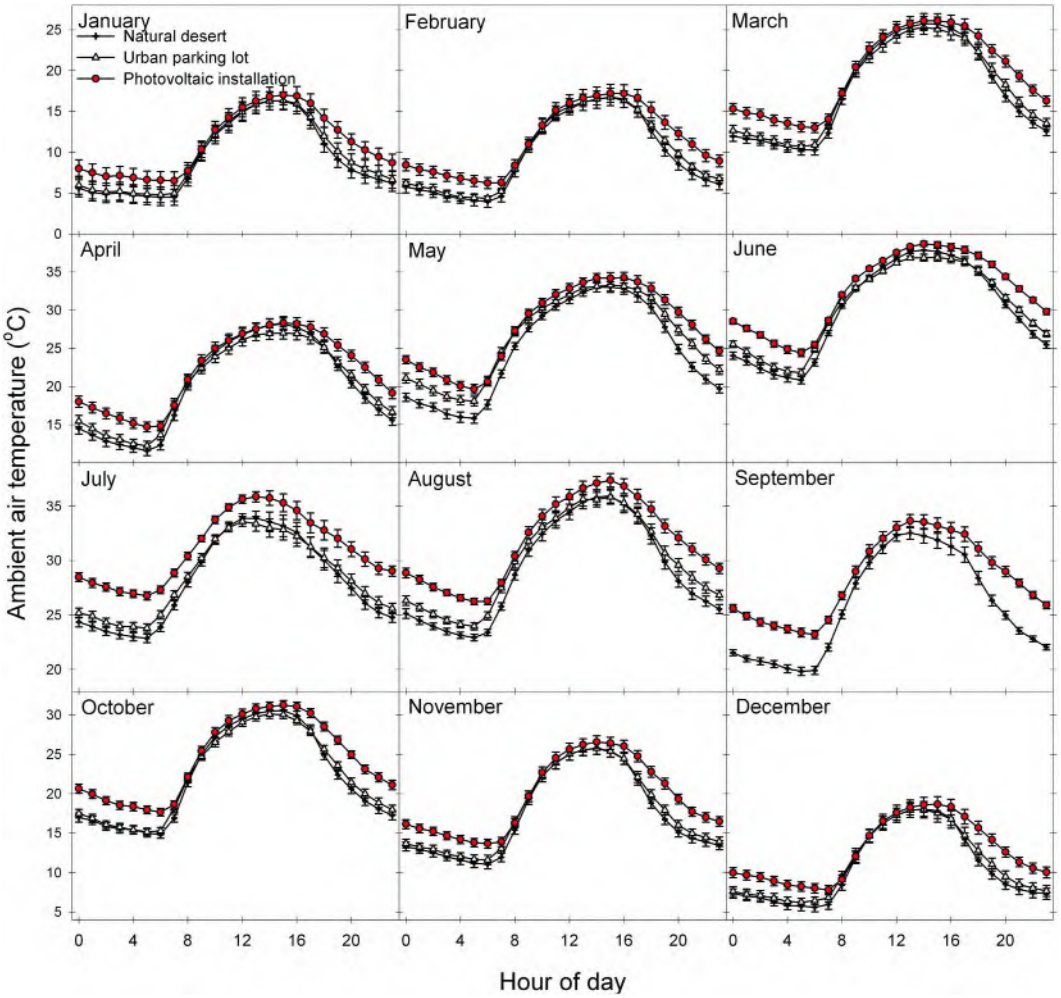

Figure 2. Average monthly ambient temperatures throughout a 24-hour period provide evidence of a photovoltaic heat island (PVHI) effect.

In both PVHI and UHI scenarios, the greater amount of exposed ground surfaces compared to natural systems absorbs a larger proportion of high-energy, shortwave solar radiation during the day. Combined with minimal rates of heat-dissipating transpiration from vegetation, a proportionally higher amount of stored energy is reradiated as longwave radiation during the night in the form of sensible heat (Fig. 1)[15]. Because PV installations introduce shading with a material that, itself, should not store much incoming radiation, one might hypothesize that the effect of a PVHI effect would be lesser than that of a UHI. Here, we found that the difference in evening ambient air temperature was consistently greater between the PV installation and the desert site than between the parking lot (UHI) and the desert site (Fig. 3). The PVHI effect caused ambient temperature to regularly approach or be in excess of 4 °C warmer than the natural desert in the evenings, essentially doubling the temperature increase due to UHI measured here. This more significant warming under the PVHI than the UHI may be due to heat trapping of re-radiated sensible heat flux under PV arrays at night. Daytime differences from the natural ecosystem were similar between the PV installation and urban parking lot areas, with the exception of the Spring and Summer months, when the PVHI effect was significantly greater than UHI in the day. During these warm seasons, average midnight temperatures were 25.5 + 0.5 °C in the PV installation and 23.2 + 0.5 °C in the parking lot, while the nearby desert ecosystem was only 21.4 + 0.5 °C.

The results presented here demonstrate that the PVHI effect is real and can significantly increase temperatures over PV power plant installations relative to nearby wildlands. More detailed measurements of the underlying causes of the PVHI effect, potential mitigation strategies, and the relative influence of PVHI in the context of the intrinsic carbon offsets from the use of this renewable energy are needed. Thus, we raise several new questions and highlight critical unknowns requiring future research.

What is the physical basis of land transformations that might cause a PVHI?

We hypothesize that the PVHI effect results from the effective transition in how energy moves in and out of a PV installation versus a natural ecosystem. However, measuring the individual components of an energy flux model remains a necessary task. These measurements are difficult and expensive but, nevertheless, are indispensable in identifying the relative influence of multiple potential drivers of the PVHI effect found here. Environmental

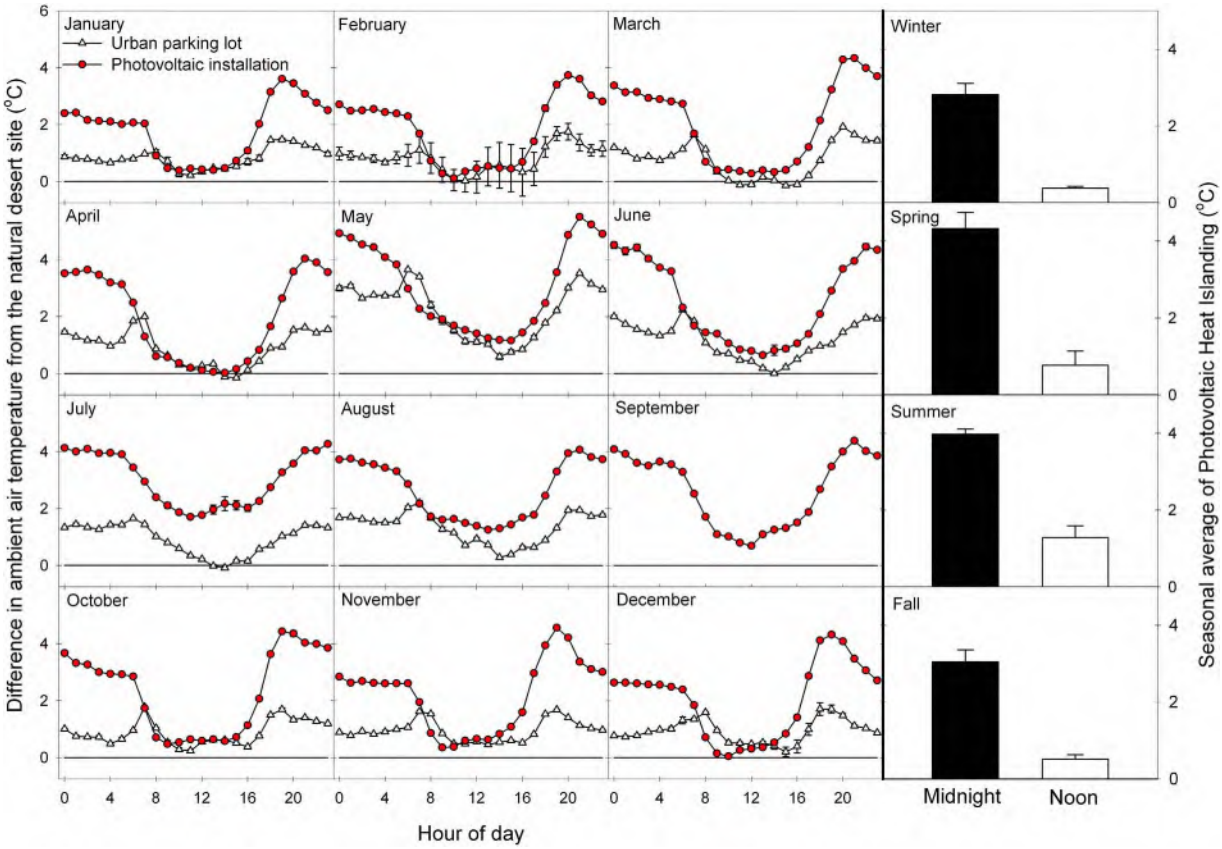

Figure 3. (Left) Average monthly levels of Photovoltaic Heat Islanding (ambient temperature difference between PV installation and desert) and Urban Heat Islanding (ambient temperature difference between the urban parking lot and the desert). (Right) Average night and day temperatures for four seasonal periods, illustrating a significant PVHI effect across all seasons, with the greatest influence on ambient temperatures at night.

conditions that determine patterns of ecosystem carbon, energy, and water dynamics are driven by the means through which incoming energy is reflected or absorbed. Because we lack fundamental knowledge of the changes in surface energy fluxes and microclimates of ecosystems undergoing this land use change, we have little ability to predict the implications in terms of carbon or water cycling[4,8].

What are the physical implications of a PVHI, and how do they vary by region?

The size of an UHI is determined by properties of the city, including total population[26–28], spatial extent, and the geographic location of that city[29–31]. We should, similarly, consider the spatial scale and geographic position of a PV installation when considering the presence and importance of the PVHI effect. Remote sensing could be coupled with ground-based measurements to determine the lateral and vertical extent of the PVHI effect. We could then determine if the size of the PVHI effect scales with some measure of the power plant (for example, panel density or spatial footprint) and whether or not a PVHI effect reaches surrounding areas like wildlands and neighborhoods. Given that different regions around the globe each have distinct background levels of vegetative ground cover and thermodynamic patterns of latent and sensible heat exchange, it is possible that a transition from a natural wildland to a typical PV power plant will have different outcomes than demonstrated here. The paucity in data on the physical effects of this important and growing land use and land cover change warrants more studies from representative ecosystems.

What are the human implications of a PVHI, and how might we mitigate these effects?

With the growing popularity of renewable energy production, the boundaries between residential areas and larger-scale PV installations are decreasing. In fact, closer proximity with residential areas is leading to increased calls for zoning and city planning codes for larger PV installations[32,33], and PVHI-based concerns over potential reductions in real estate value or health issues tied to Human Thermal Comfort (HTC)[34]. Mitigation of a PVHI effect through targeted revegetation could have synergistic effects in easing ecosystem degradation associated with development of a utility scale PV site and increasing the collective ecosystem services associated with an area[4]. But what are the best mitigation measures? What tradeoffs exist in terms of various means of revegetating degraded PV installations? Can other albedo modifications be used to moderate the severity of the PVHI?

Figure 4. Experimental sites. Monitoring a (1) natural semiarid desert ecosystem, (2) solar (PV) photovoltaic installation, and (3) an "urban" parking lot – the typical source of urban heat islanding – within a 1 km^2 area enabled relative control for the incoming solar energy, allowing us to quantify variation in the localized temperature of these three environments over a year-long time period. The Google Earth image shows the University of Arizona's Science and Technology Park's Solar Zone.

To fully contextualize these findings in terms of global warming, one needs to consider the relative significance of the (globally averaged) decrease in albedo due to PV power plants and their associated warming from the PVHI against the carbon dioxide emission reductions associated with PV power plants. The data presented here represents the first experimental and empirical examination of the presence of a heat island effect associated with PV power plants. An integrated approach to the physical and social dimensions of the PVHI is key in supporting decision-making regarding PV development.

Methods

Site Description. We simultaneously monitored a suite of sites that represent the traditional built urban environment (a parking lot) and the transformation from a natural system (undeveloped desert) to a 1 MW PV power plant (Fig. 4; Map data: Google). To minimize confounding effects of variability in local incoming energy, temperature, and precipitation, we identified sites within a 1 km area. All sites were within the boundaries of the University of Arizona Science and Technology Park Solar Zone (32.092150°N, 110.808764°W; elevation: 888 m ASL). Within a 200 m diameter of the semiarid desert site's environmental monitoring station, the area is composed of a sparse mix of semiarid grasses (*Sporobolus wrightii, Eragrostis lehmanniana*, and *Muhlenbergia porteri*), cacti (*Opuntia* spp. and *Ferocactus* spp.), and occasional woody shrubs including creosote bush (*Larrea tridentata*), whitethorn acacia (*Acacia constricta*), and velvet mesquite (*Prosopis velutina*). The remaining area is bare soil. These species commonly co-occur on low elevation desert bajadas, creosote bush flats, and semiarid grasslands. The photovoltaic installation was put in place in early 2011, three full years prior when we initiated monitoring at the site. We maintained the measurement installations for one full year to capture seasonal variation due to sun angle and extremes associated with hot and cold periods. Panels rest on a single-axis tracker system that pivot east-to-west throughout the day. A parking lot with associated building served as our "urban" site and is of comparable spatial scale as our PV site.

Monitoring Equipment & Variables Monitored. Ambient air temperature (°C) was measured with a shaded, aspirated temperature probe 2.5 m above the soil surface (Vaisala HMP60, Vaisala, Helsinki, Finland in the desert and Microdaq U23, Onset, Bourne, MA in the parking lot). Temperature probes were cross-validated for precision (closeness of temperature readings across all probes) at the onset of the experiment. Measurements of temperature were recorded at 30-minute intervals throughout a 24-hour day. Data were recorded on a data-logger (CR1000, Campbell Scientific, Logan, Utah or Microstation, Onset, Bourne, MA). Data from this

instrument array is shown for a yearlong period from April 2014 through March 2015. Data from the parking lot was lost for September 2014 because of power supply issues with the datalogger.

Statistical analysis. Monthly averages of hourly (on-the-hour) data were used to compare across the natural semiarid desert, urban, and PV sites. A Photovoltaic Heat Island (PVHI) effect was calculated as differences in these hourly averages between the PV site and the natural desert site, and estimates of Urban Heat Island (UHI) effect was calculated as differences in hourly averages between the urban parking lot site and the natural desert site. We used midnight and noon values to examine maximum and minimum, respectively, differences in temperatures among the three measurement sites and to test for significance of heat islanding at these times. Comparisons among the sites were made using Tukey's honestly significant difference (HSD) test[35]. Standard errors to calculate HSD were made using pooled midnight and noon values across seasonal periods of winter (January-March), spring (April-June), summer (July-September), and fall (October-December). Seasonal analyses allowed us to identify variation throughout a yearlong period and relate patterns of PVHI or UHI effects with seasons of high or low average temperature to examine correlations between background environmental parameters and localized heat islanding.

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Author Contributions

G.A.B.-G., R.L.M. and N.A.A. established research sites and installed monitoring equipment. G.A.B.-G. directed research and R.L.M. conducted most site maintenance. G.A.B.-G., N.A.A., A.D.C. and M.A.P.-Z. led efforts to secure funding for the research. All authors discussed the results and contributed to the manuscript.

Additional Information

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RESEARCH ARTICLE

Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency

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Abstract

Power demands are set to increase by two-fold within the current century and a high fraction of that demand should be met by carbon free sources. Among the renewable energies, solar energy is among the fastest growing; therefore, a comprehensive and accurate design methodology for solar systems and how they interact with the local environment is vital. This paper addresses the environmental effects of solar panels on an unirrigated pasture that often experiences water stress. Changes to the microclimatology, soil moisture, water usage, and biomass productivity due to the presence of solar panels were quantified. The goal of this study was to show that the impacts of these factors should be considered in designing the solar farms to take advantage of potential net gains in agricultural and power production. Microclimatological stations were placed in the Rabbit Hills agrivoltaic solar arrays, located in Oregon State campus, two years after the solar array was installed. Soil moisture was quantified using neutron probe readings. Significant differences in mean air temperature, relative humidity, wind speed, wind direction, and soil moisture were observed. Areas under PV solar panels maintained higher soil moisture throughout the period of observation. A significant increase in late season biomass was also observed for areas under the PV panels (90% more biomass), and areas under PV panels were significantly more water efficient (328% more efficient).

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1 Introduction

Global energy demand will be doubled by mid-century due to population and economic growth [1,2]. Renewable and environmental-friendly energies will play a vital role to meet this demand.

Among all renewable energies, solar power is the most abundant and available source [3]. Solar power is also becoming more affordable. The cost of solar panels has fallen by 10% per year for the past thirty years, while production has risen by 30% per year. If costs continue to be reduced based on this historic rate, solar energy will be less expensive than coal by 2020[4]. The impact of wide-spread solar installations is an area of increasing interest. Regional

Competing interests: The authors have declared that no competing interests exist.

climatology may be influenced by large scale solar installations, but simulations have provided conflicting results: 3–4˚C *increase* in air temperature over solar panels compared to wildlands at night [5], 0.1–0.5˚C *decrease* in air temperature [6], 26˚C *increase* in the shaded roof top temperature compared with unshaded roof top [7], 1–2.5˚C increase in regional and global temperatures in urban area [8] and a 5.2˚C *increase* in air temperature under solar panels [9].

Solar installations can occupy large land areas and sometimes compete with agriculture for the land resource [10]. Agrivoltaic systems are created when solar and agricultural systems are co-located for mutual benefit. The formal introduction of agrivoltaic systems is credited to Dupraz in 2011 [11]. Land demand for energy production decreases profoundly when agrivoltaics are used [10]. Not all agricultural crops are suitable, but plants with less root density and a high net photosynthetic rate are ideal candidates [11]. Agrivoltaic systems have been shown to increase land productivity by 60–70% [12], and increase the value of energy production system by 30% [13]. Very limited experimental research was found on the impacts of a solar arrays on agricultural production. Marrou et al. [14] measured soil water potential and soil water gradient (difference between uptake and drainage) in cucumber and lettuce and revealed lower soil water potential under the panels. This water potential led to an increase in harvested final fresh weight. Another experiment by Marrou et el. [15] found that plants cover soil faster under the shade of solar panels. An experimental study by Dupraz et al. demonstrated that summer crops benefited of solar shade more than winter crops such as pea and wheat crops [16]. Co-locating agave plant below solar panels increased yield per m^3 of water used in the San Bernardino County in California [17]. Non-beneficial effects have also been observed in Welch onion fields where, photovoltaics reduced the fresh and dry matter harvest weight [18].

In this paper, a field study was performed to measure the effects of a six-acre agrivoltaic solar farm on the microclimatology, soil moisture and pasture production. The experimental setup included microclimatological and soil moisture measurements from May to August 2015 in Rabbit Hills agrivoltaic solar arrays, located on the Oregon State University campus. The field data for this study is accessible through Oregon State library system [19].

2 Material and methods

The field study was performed on a six acre agrivoltaic solar farm and sheep pasture near the Oregon State University Campus (Corvallis, Oregon, US.). The PhotoVoltaic Panels (PVPs) have been arranged in east–west orientated strips, 1.65 m wide and inclined southward with a tilt angle of 18°. PVPs have been held at 1.1 meters above ground (at lowest point) and the distance between panels is 6 meters as shown in Fig 1) e. The whole solar array system has a capacity of 1435 kilowatts (http://fa.oregonstate.edu/sustainability/ground-mounted-photovoltaic-arrays). As shown in Fig 1, the data were collected from localized zones (described hereafter) including areas below solar panels and a control area outside the agrivoltaic system. The pasture below the solar panels and the control areas were in the same paddock that was actively grazed by sheep. Exclusionary plots, to eliminate grazing pressure, were maintained with fencing. The total size of the fenced areas was limited by agricultural activities. The pasture was not irrigated, and typically experiences water stress mid-summer. The soil classification for >70% of the pasture area (control and agrivoltaic system) is Woodburn Silt clay [20]. The control and treatment plots were located within Woodburn Silt clay classification areas. The intent of the field measurements was to minimize uncontrollable differences between the treatments and control (e.g. solar forcing, soil types) and minimize impact on agricultural activities. Thus, the distance between the treatment site and the control site was kept minimum. The observations within the treatment site were further divided into three sub-treatments (Fig 2): (1) Sky Fully Open area between panels (SFO), (2) Solar Partially Open

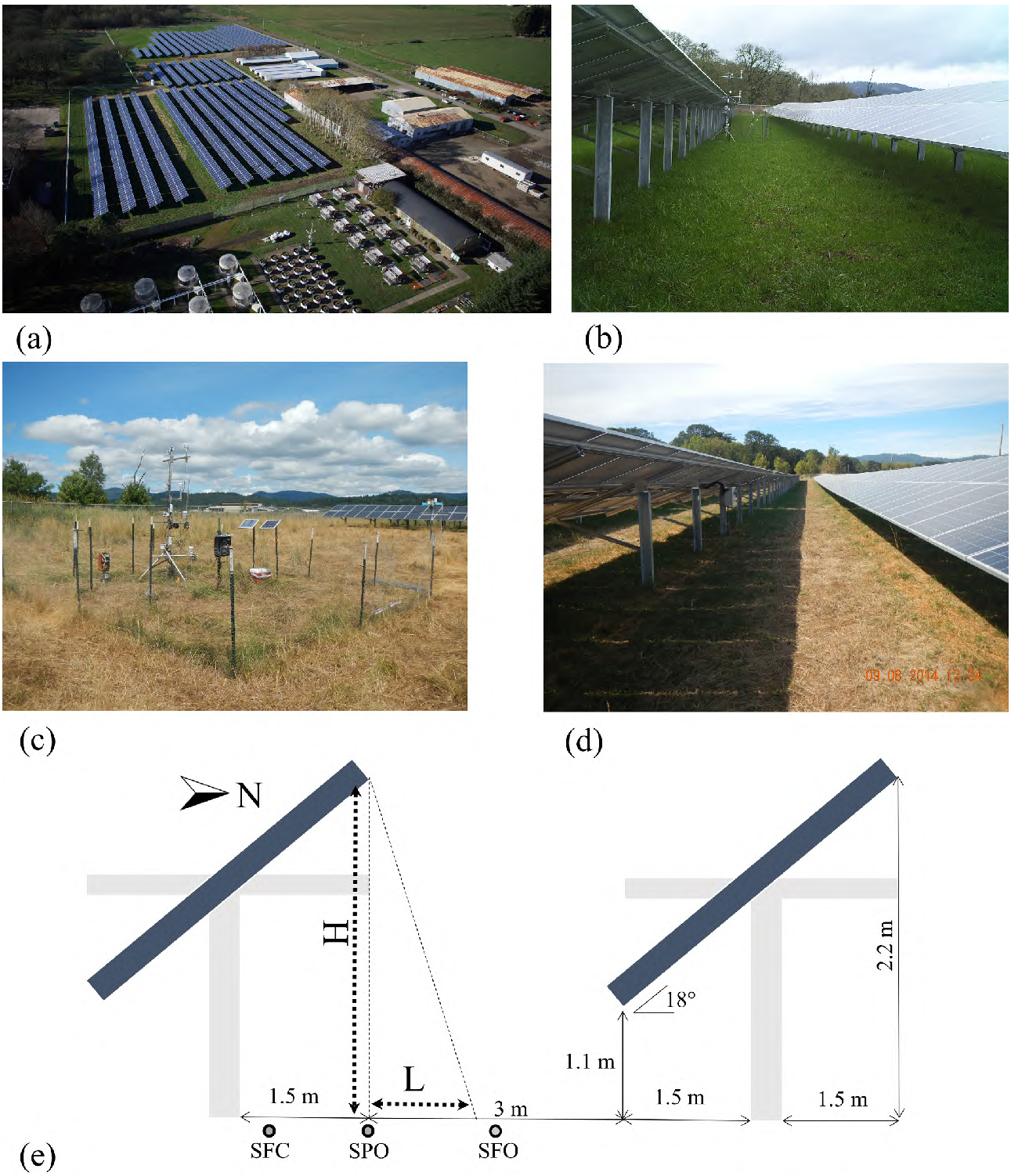

Fig 1. a) Aerial photo of 35th Street agrivoltaic solar array, Oregon State University Corvallis campus (this photo is taken in winter and shadow pattern is different from the measurements which held in summer) Copyright: Oregon State University, b) Solar panel set up, c) Control area set up, d) Shade zones in solar panel, e) Schematic drawing of shade zones (H is object height and L is shadow length).

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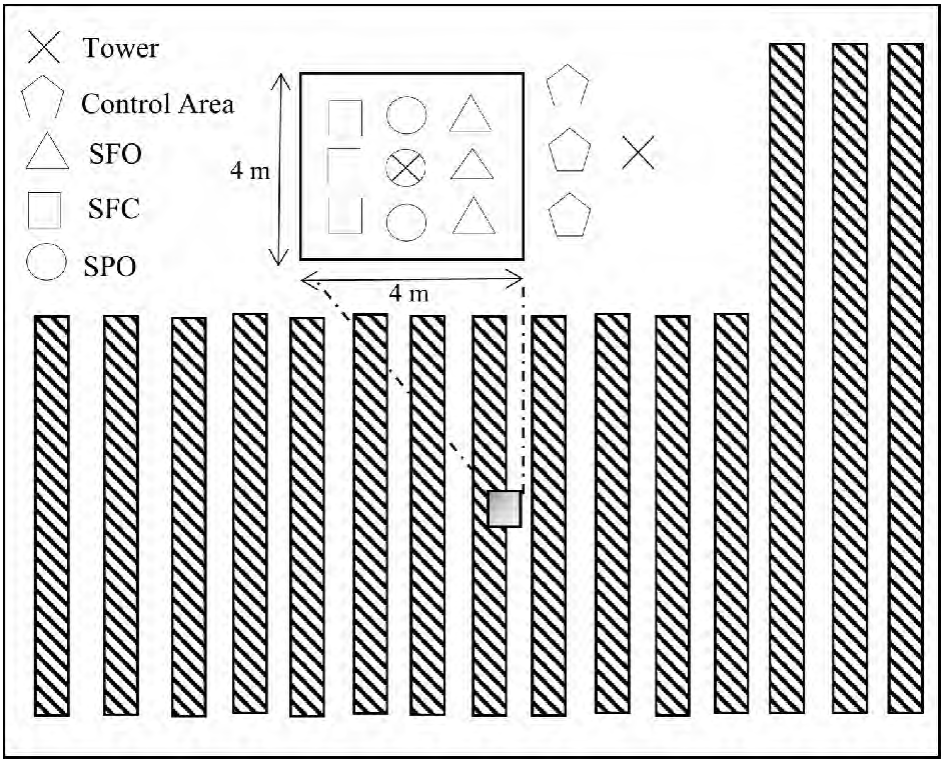

Fig 2. Plan view of experimental setup in solar array area showing locations of towers and neutron probe access tubes for: Solar Fully Covered (SFC), Solar partially open (SPO), Sky Fully Open (SFO), solar measurements are almost 70 meters apart from control area.

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between panels (SPO) and (3) Solar Fully Covered area under panels (SFC). SFO areas are between the edges of installed PV panels and experienced full sun. Shadow length calculation also confirms no shade covers the SFO zone [21]. SPO areas are in the penumbra and experienced episodic shade. SFC areas are directly beneath the PV panels and experienced full shade. Data from these sub-treatments were compared to the data collected from the control area outside the agrivoltaic array, where each measurement was replicated.

Shadow length (L) is calculated [20]based on the sun latitude, solar panel height, day and time of the year the and it changes from 1.1 meters to 1.4 meters for May, June, July and August of 2015 which makes the SFO no shadow zone.Data were collected continuously in all areas from May-August 2015. Air temperature, relative humidity, wind speed and wind direction measurements were collected on 1 minute intervals. Soil moisture profiles were collected three times each week, and biomass samples were collected at the end of the observation period. Details associated with each set of measurements are explained in the following subsections.

2.1 Microclimatological measurements

Two atmospheric profiling stations were installed 70 meters apart: one in the control area and one near the center of the solar panel area. Micrometeorological variables were collected at four levels (0.5, 1.2, 2.0 and 2.7 m aboveground) in 1 minute intervals. The gathered variables were (1) air temperature (VP-3 Decagon Devices), (2) wind speed and directions (DS-2 Decagon Devices), (3) relative humidity (VP-3 Decagon Devices) and (4) net radiation (PYR

Decagon Devices). Data were logged on EM50 data loggers (Decagon Devices). Temperature and humidity devices were calibrated in a chamber, and wind sensors were calibrated in a wind tunnel prior to installation. A Kolmogorov Smirnov test was used to detect differences in *distributions* of temperature, humidity, wind speed, wind direction, and down welling radiation between the solar array area and the control area. A two tailed t-test was used to detect differences in the *mean* temperature, humidity, wind speed, wind direction, and down welling radiation between the solar array area and the control area and standard deviation results was measured to quantify the amount of dispersion of a set of data values.

2.2 Soil moisture measurement

The soil moisture was obtained using a neutron probe device (503 DR hydro-probe Campbell Pacific Nuclear International Inc. BoartLongyear Corporation (CPN), Concord, California, USA). These data were gathered at six depths for each sampling location (0.1 m to 0.6 m in 0.1 m intervals). Fig 2 shows a plan view where nine neutron probe access tubes for soil moisture measurements were installed in the solar area. Three access tubes were installed in each sub-treatment: SFO, SPO, and SFC respectively. Three access tubes were also installed in the control area. Neutron Probe readings were taken approximately every three days. A standard count was taken prior to sampling each day to calibrate data readings. Three neutron counts were averaged for each individual measurement (a single depth in a single tube). This count was normalized by the standard count, and the normalized count was calibrated to soil moisture. Within each sub-treatment, data at the same depths are averaged to determine the soil moisture profile and error-bars. The result is a soil moisture profile with measurements at 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 m for each sub-treatment and the control every three days. Neutron probe readings at the 0.1m depth for all sub-treatments and the control were adjusted to account for possible neutron losses to the atmosphere [22]. Two-way ANOVA was used to test the independence of the soil moisture measurements with respect to zoning (the control, SFO, SPO, and SFC) and depth.

2.3 Biomass measurements

Above-ground biomass was collected on the 28th of August. Six 1m by 1m quadrants were collected from within the fenced areas for each sub-treatment and the control. Harvested biomass was dried for 48 hours in a 105 ^{o}C oven and weighed. The Daubenmire method [11] was used to study grass species diversity at the end of July. Six transects in the control and one transect in the solar array were performed. For each transect, a random number was drawn (from 1–10) to determine the final location of each 1m x1m quadrant. Six quadrants were collected in each transect resulting in a total of 42 samples. In each quadrant, the coverage, by species, was determined visually.

3 Results and discussions

3.1 Micrometeorological variables

Using a Kolmogorov Smirnov test, a two tailed t-test, standard deviation and William Watson test[23] for wind direction showed subtle but statistically significant differences. Significant differences in mean temperature were found in readings taken closest to the PV panel surfaces at the 1.2 m and 2.0 m elevations. No significant differences were observed at the lowest (0.5 m) or highest (2.7 m) elevations. Note that the magnitude of these mean temperature differences are smaller than those reported from simulation studies [5–9]. Significant differences in mean relative humidity and wind speed were found for all measurement heights. Solar

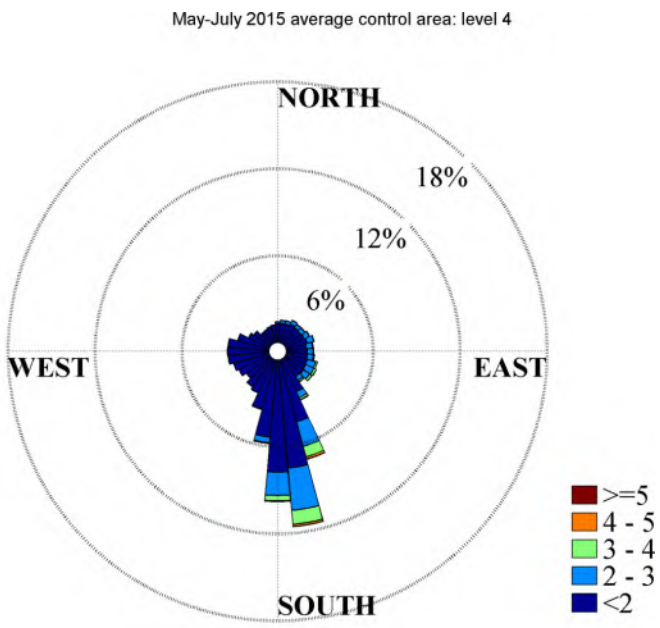
Table 1. Mean/Std and p-values from solar panel and control area Two-sample Kolmogorov-Smirnov, t tests and William Watson test.

Elevation (m)		0.5	1.2	2.0	2.7
Temperature (˚C)	Mean/Std (solar panel area)	18.34/7.87	18.03/8.06	18.30/7.39	18.37/7.65
	Mean/Std (control area)	18.27/7.85	18.32/8.31	18.36/7.47	18.11/7.64
	p-values (KS test)	0.9964	0.9964	1.0000	1.0000
	p-values (t test)	0.1527	**0.0000**	**0.0000**	0.5996
Relative humidity (%)	Mean/Std (solar panel area)	65.62/0.226	64.17/0.252	64.29/0.209	64.92/0.230
	Mean/Std (control area)	66.23/0.234	66.38/0.242	64.89/0.222	65.37/0.223
	p-values (KS test)	**0.0004**	0.3611	0.7014	0.6703
	p-values (t test)	**0.0000**	**0.0000**	**0.0000**	**0.0118**
Wind speed (m/s)	Mean/Std (solar panel area)	0.5471/0.506	0.4880/0.427	1.3777/1.083	1.0889/0.909
	Mean/Std (control area)	0.8752/0.665	0.6384/0.520	1.1313/0.859	0.9726/0.757
	p-values (KS test)	0.9579	1.0000	0.8497	0.9964
	p-values (t test)	**0.0000**	**0.0000**	**0.0000**	**0.0000**
Solar radiation (W/m2)	Mean/Std (solar panel area)	-	59.53/96.65	-	275.72/322.59
	Mean/Std (control area)	-	328.26/407.93	-	271.58/323.34
	p-values (KS test)	-	**0.0099**	-	0.9597
	p-values (t test)	-	**0.0000**	-	**0.0054**
Wind direction (˚)	Mean/Std (solar panel area)	196.29/107.71	220.96/102.32	211.83/101.68	206.11/96.65
	Mean/Std (control area)	210.54/102.29	196.82/121.16	211.87/95.91	182.13/115.97
	p-values (WW test)	**0.0000**	**0.0000**	**0.0000**	**0.0000**

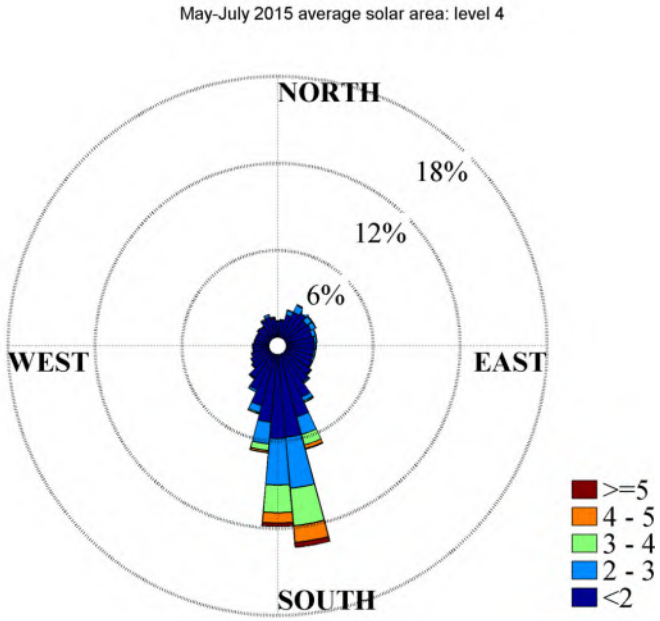
https://doi.org/10.1371/journal.pone.0203256.t001

radiation below the solar panel installation height was significantly reduced (as expected) and the incoming solar radiation measured at a height above the solar panels was found to be statistically significant (unexpected) but the difference relatively small. The distribution of wind direction was significantly altered at all heights, and the mean wind speed was significantly different at all heights. A summary of the p-values from all statistical tests is shown in Table 1. Standard deviation values were big due to diurnal changes of micro climate variables during the day.

Wind direction data at 2.7 m above ground level is shown in Fig 3 to illustrate the alterations in the wind direction. For the sake of brevity, only one height is presented in this manuscript, but all heights are shown in Supporting Information (Figure A in S1 Appendix). Fig 3 shows a histogram of incident wind direction plotted as a function of direction. Longer spokes indicate that that particular direction is more probable. Each spoke is divided and colored according to the strength of the wind (wind speed). For example, a long blue spoke would indicate that light winds from that direction are common. We can conclude from Fig 3 that the wind direction in the control area is distributed among many incident angles, while the wind direction within the treatment is oriented predominantly from the south. That is, the wind direction within the treatment area reorients with solar panels such that the wind is from south to north. The panels do not act as 'canyons' and orient the wind along their rows (a common occurrence in urban flows for example)[24]. Rather, the wind is reoriented perpendicular to the solar array's rows. The authors believe that the local increase in temperature near the solar panel surface results in a buoyant force that causes local anabatic flow up the panel surfaces. Each anabatic flow on each PV row has a vector component perpendicular to the solar panel row orientation, and the entire solar farm acts like a 'Fresnel slope' that reorients the flow. The total buoyant force is enough to accelerate the flow directionally, and contributes the increase in wind speed above the panels. Flow acceleration around a bluff body (PV panel) also contributes to increased wind speed above the solar panels. Increased drag due to the


May-July 2015 average control area: level 4
NORTH
18%
12%
6%
WEST
EAST
SOUTH
>=5
4 - 5
3 - 4
2 - 3
<2

(a)


May-July 2015 average solar area: level 4
NORTH
18%
12%
6%
WEST
EAST
SOUTH
>=5
4 - 5
3 - 4
2 - 3
<2

(b)

Fig 3. Wind rose plots for control (upper) and solar areas (lower) for May-August average wind directions. The data are for elevation 2.7 m.

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'solar canopy' is likely the cause of the reduced speed below the solar panels. Note that the most common wind speeds are weak (<2m/s), and it is unclear if this wind direction shift would be a robust result for windy locations. Higher wind speeds are also observed to reorient in Fig 3; however, the number of occurrences are limited.

3.2 Soil moisture data comparisons

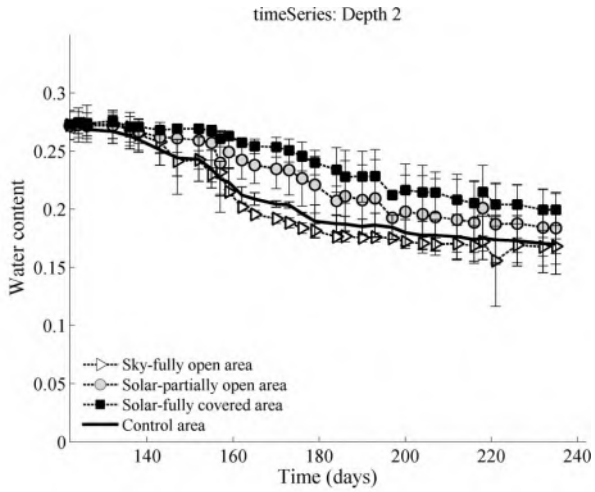
The horizontal axis shows the Day of Year (DoY) of the data collection in 2015 and vertical axis is the volumetric soil moisture in vol/vol. Independence was determined with a p-value of less than 0.01 for all depths and zones by two-way ANOVA test. The soil moisture is near saturation for all depths and all treatments at the start of observation. That is, all areas had nearly identical initial soil moistures. The differing rates of soil water depletion in the three sub-treatments and the control led to dramatic differences in late season soil moisture.

The soil moisture in the SFO area is depleted more rapidly than the SPO, SFC or control areas. This result is intriguing since the SFO area and the control experience similar incident solar radiation. Thus, the SFO must have a different energetic balance despite similar exposure to direct solar energy. We hypothesize that this difference in rate of soil moisture loss is a result of the longwave radiation transfer. The SFO will experience incident long wave radiation from the adjacent PV panels. These PV panels would also reduce the sky view factor of the SFO area. In contrast, the sky view in the control area is unobstructed. Thus, we infer that the total net long wave and net shortwave radiation both play an important role in the energetics and evaporation in the SFO area. The complete long and short wave radiation budgets within an agrivoltaic system will be explored in future study.

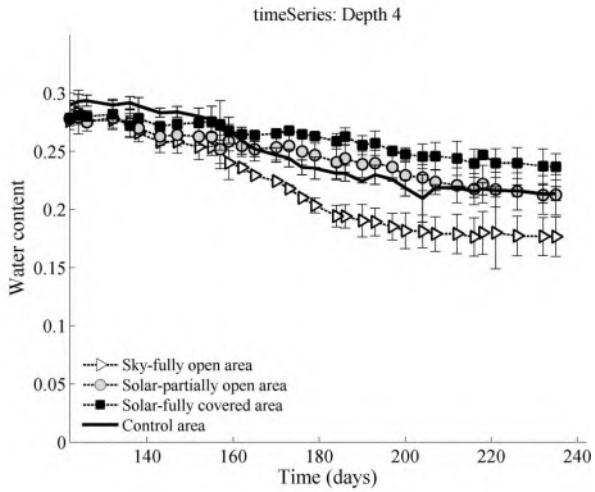
Time series of the soil moisture at 0.2 m, 0.4 m and 0.6 m are presented in Fig 4 in subpanels a-c. Time series of soil moisture at 0.1 m, 0.3 m and 0.5 m can be found in Supporting Information (Figure A in S2 Appendix). Soil moisture is most persistent in the SFC area and remains available for a larger portion of the growing season. The soil moisture at 0.6 m depth remained close to saturation (0.3 vol/vol) for the entire season which implies that water is available at the bottom of the root zone over the period of observation Fig 4C. Overall the SFC area remained wetter than all other areas, including the control. This water availability is in stark contrast to the SFO area which was near saturation at the start of observation (~0.3 vol/vol) and depleted to ~0.2 vol/vol at the end of the season. This stark contrast in the moisture availability between the SFO and SFC creates an undesirable variability across the field and hints that shade uniformity may be an important consideration for the design of future agrivoltaic systems. The SPO area dries at a rate slower than the SFO but faster than the SFC and the control.

In other words, for most times and soil depths, the SFC had that highest soil moisture followed by the SPO, control and SFO respectively. It should be noted that the mean soil moisture across the SPO, SFO and SFC regions is similar to the control. But, the solar panels increase the local heterogeneity of soil water conditions, which results in some areas (SFC) having more persistent stores of soil water throughout the growing season.

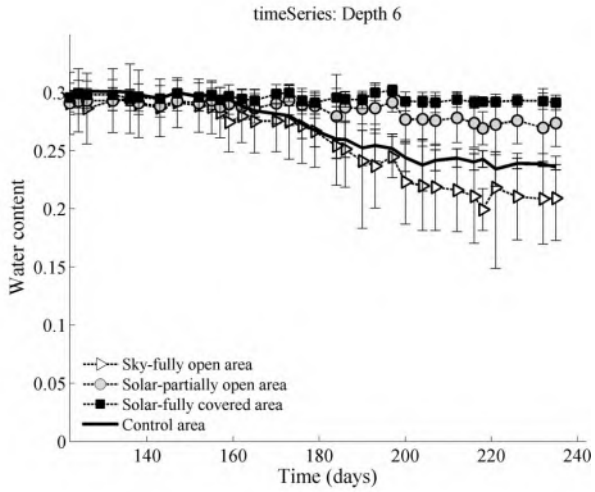
The soil profiles at the beginning and end of the observation period are shown in Fig 5 All areas were near saturation for all depths initially. By the end of the observation period, the soil moisture in the SFC zone was nearly twice the SFO. These measurements are separated by less than two meters spatially. All measured soil moisture profiles are available in Supporting Information (Figure A in S3 Appendix).



(a)



(b)



(c)

Fig 4. Soil moisture time series (a) 0.2m, (b) 0.4m and (c) 0.6m. For more information: there was 40 mm precipitation over the observation period, i.e. May-Aug 2015.

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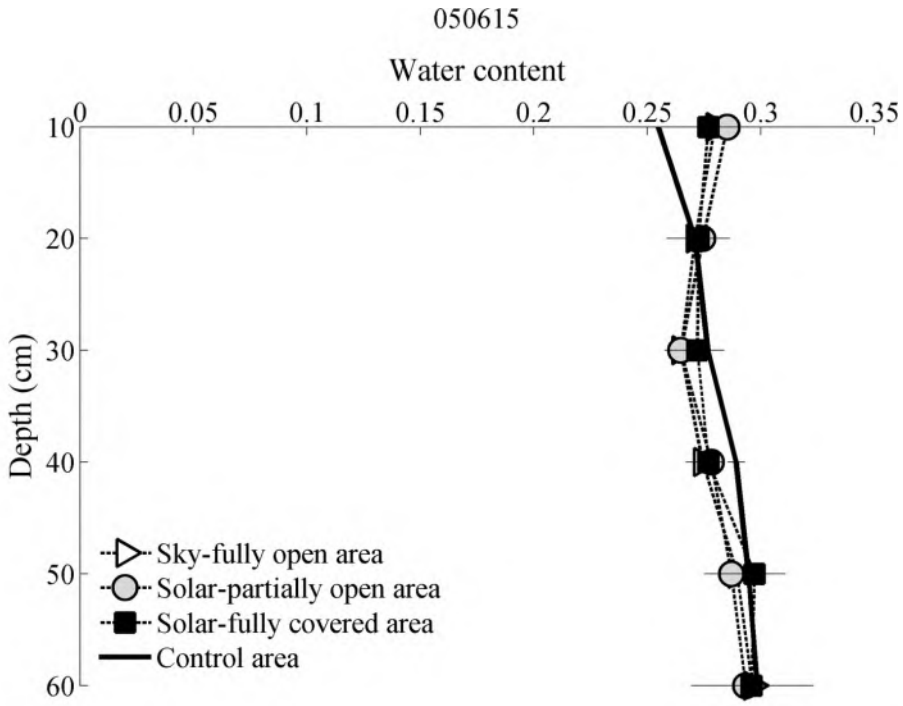
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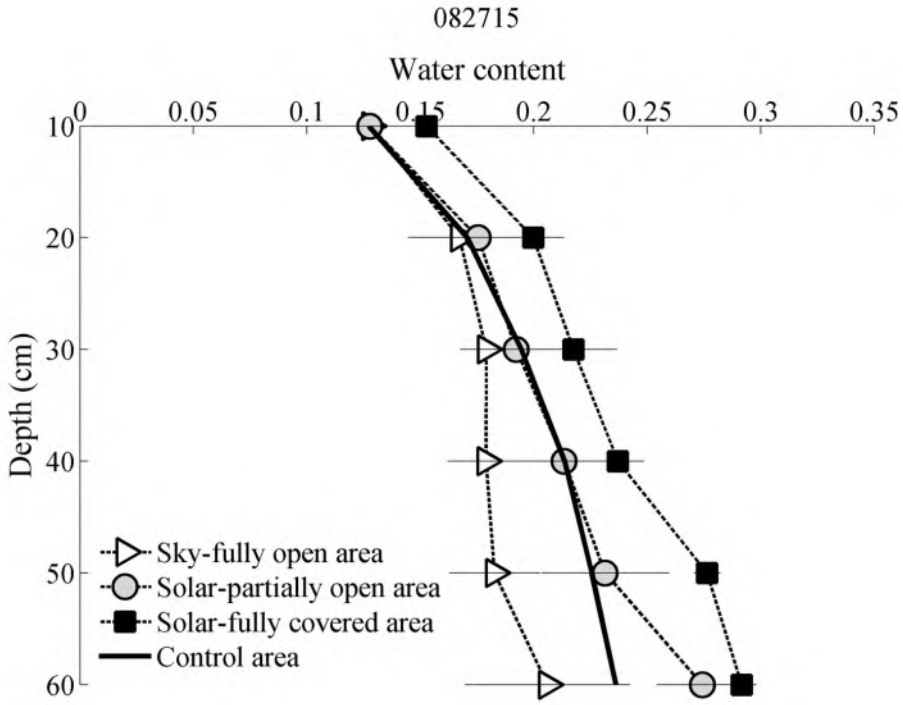
Water content
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Depth (cm)
10
20
30
40
50
60
Sky-fully open area
Solar-partially open area
Solar-fully covered area
Control area

(a)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Water content
0
0.05
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0.2
0.25
0.3
0.35
Depth (cm)
10
20
30
40
50
60
Sky-fully open area
Solar-partially open area
Solar-fully covered area
Control area

(b)

Fig 5. Selected normalized soil moisture profiles from data sampling to show the change in soil moisture through growing season, (a) May 06–2015 and (b) August 27–2015.

https://doi.org/10.1371/journal.pone.0203256.g005

3.3 Vegetation

Eight grass types were identified in the control pasture and five were identified in the solar farm area. A summary of the results is presented in Table 2. The most common species in the solar panel area was Alopecurus, a long-lived perennial that thrives in moist conditions. Alopecurus provides a "succulent and palatable forage" [25]. The most prevalent grass type in control area is Hordeum that has spikelet clusters that can enter nostrils and ear canals in mammals. Three types of grasses Calamagrostis, Cirsium and Dactylis were observed only in the control area. These grasses are only favored by sheep and cattle in the early stage of the grass before spine develops [26]. The causal factor for the diversity change between control and treatment requires further investigation.

The harvested dry biomass at the end of the observation period is shown in Fig 6 Results show 126% more dry biomass in the SFC zone relative to the SFO zone and 90% more dry biomass in the SFC zone relative to the control. Although the sample size is small, difference between the SFC and the control were found to be significant, (p-value = 0.007). In addition, the difference between the SFC and the SFO were found to be significant, (p-value = 0.007).

3.4 Water usage

Water usage was calculated based on difference in depth averaged soil moisture between the beginning (Fig 5(A) and end (Fig 5(B)) of the observation period. Averages are calculated by integrating soil moisture over soil depth from 10cm to 60cm. Water Use Efficiency (WUE) is then calculated as the biomass produced per unit of water used. Water use efficiencies in kg biomass/m^3 of water against the biomass weight in control and SFO and SFC treatments are presented in Fig 7 ($\frac{\text{WUE SFC} - \text{WUE Control area}}{\text{WUE Control area}}$). The higher producing SFC treatment was also significantly more water efficient (328%).

The seasonal climate pattern at the site produces an initially saturated pasture and a a dry growing season. Initial water stores are depleted, through evapotranspiration (ET), and water scarcity occurs in the control and SFO areas. The shaded treatments (SFC and SPO) experience lower potential evapotranspiration (PET) due to decreased solar radiation throughout the observation period which resulted in a slower dry-down of the stored soil water. The decreased rate of dry-down in the SFC and SPO areas left soil water stores available throughout the observation period and allowed pasture grasses in the SFC and SPO to accumulate a significantly greater biomass. The reduced PET in the SFC and SPO treatments also contributed to

Table 2. The results of biomass monitoring for different grass types in solar and control area.

Grass scientific name (common name)	Solar area (%)	Control area (%)
Hordeum (Foxtail barely)	10	25
Agrostis (Redtop bentgrass)	30	20
Alopecurus (Meadow foxtail)	50	7
Schedonorus (Tall rye grass)	5	9
Bromus (Foxtailbrome)	5	22
Calamagrostis (Reed grass)	0	6
Cirsium (Thistle)	0	10.5
Dactylis (Orchard grass)	0	0.5

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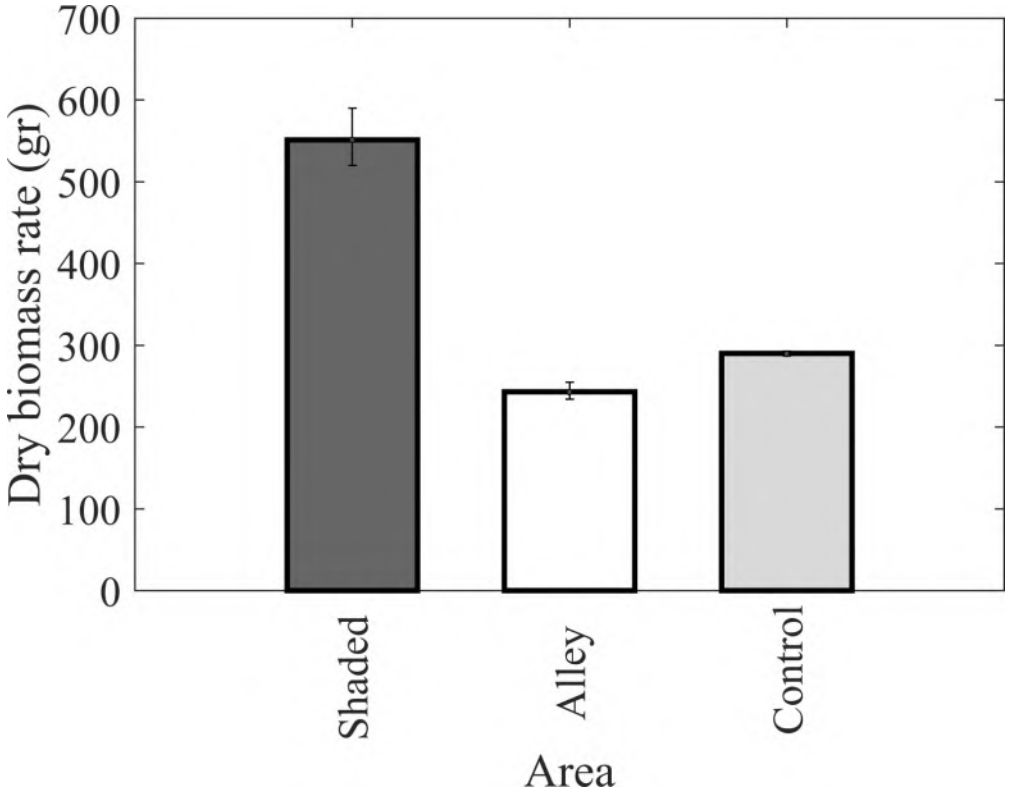

Fig 6. Dry biomass comparison in three places Solar Fully Covered (SFC), Sky Fully Open (SFO) and control area.

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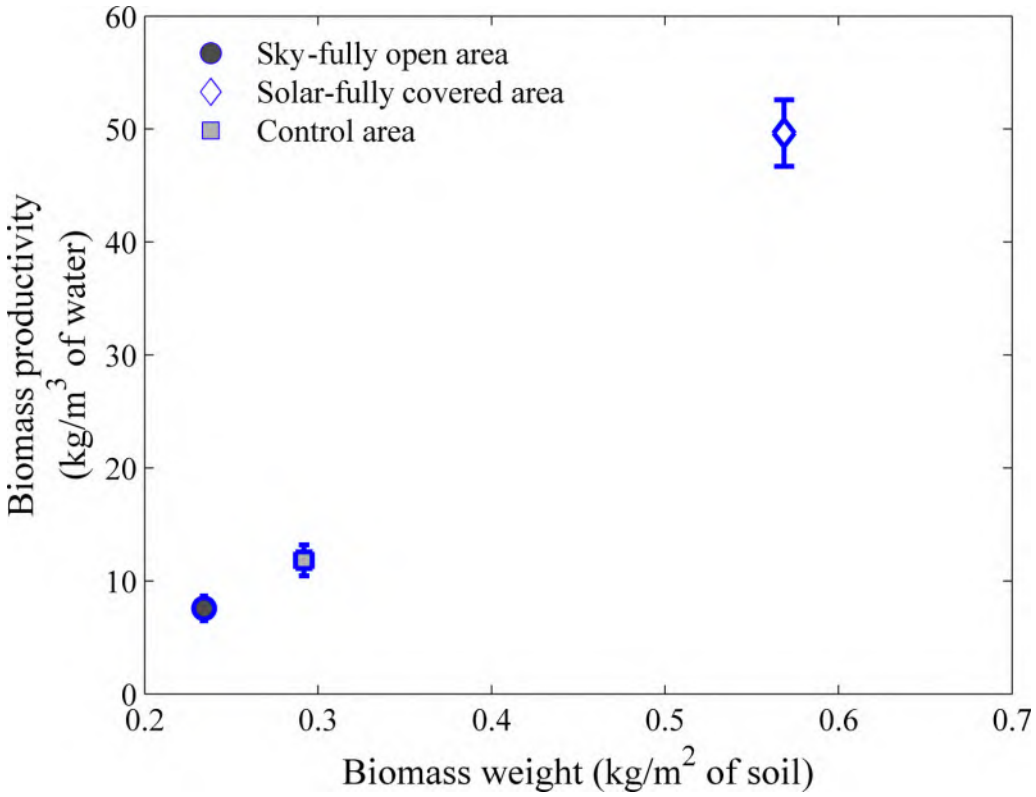

Fig 7. Biomass productivity in kg/ m^3 of water.

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an increase in water use efficiency of the pasture grasses. That is, a 'water limited' area, in a Budyiko [27] sense, could be considered as an area of 'solar excess.' By harvesting this solar excess with solar panels, PET is reduced. Taken to an extreme it is possible to shift the aridity such that the shaded area becomes energy limited. Thus there must exist a shading level, for a water limited area, where PET and AET would be in balance. We would not expect a similar outcome in 'energy limited' areas (Budyko sense) as observed by Armstrong et al. [8]. In this case, there is no solar excess and the PET is already equal to the AET. If solar arrays were placed above growing plants in 'energy limited' conditions we would expect that the total biomass production would decrease, consistent with the findings of Armstrong et al. [16].

4 Conclusion

Typical agricultural operations manage multiple on-farm resources including soil, nutrients and water. This study suggests that the on-farm solar resource management could also be implemented for productive benefits. Water limited areas are most likely to benefit as solar management reduces PET and consequently the water demand. Not all crops will be amenable to solar management, and the economics of active solar management with PV panels needs further study. But, semi-arid pastures with wet winters may be ideal candidates for agrivoltaic systems as supported by the dramatic gains in productivity (90%) observed over the May-Aug 2015 observation period at the Rabbit Hills agrivoltaic solar array. These net benefits were largely achieved through an increased water use efficiency in the shaded areas of the field which left water stored in the soil column available throughout the entire observation period. Extreme heterogeneity and spatial gradients in biomass production and soil moisture were observed as a result of the heterogeneous shade pattern of the PV array. Future agrivoltaic designs should eliminate this heterogeneity by optimizing PV panel placement to create a spatially uniform shadow pattern. A spatially uniform shadow pattern would foster uniform biomass accumulation benefits. The agricultural benefits of energy and pasture co-location could reduce land competition and conflict between renewable energy and agricultural production. Reduced or eliminated land completion would open new areas for PV installation. Local climatic effects of agrivoltaic installations were statistically significant but subtle, however the regional climatic impacts (e.g. rainfall patterns) of large scale agrivoltaic instillations are still unclear and should be the subject of further study.

Supporting information

S1 Appendix. Figure A: Wind rose plots for four level heights.
(DOCX)

S2 Appendix. Figure A: Soil moisture time series (a) 0.1m, (b) 0.3m and (c) 0.5m. For more information: there was 40 mm precipitation over the observation period, i.e. May-Aug 2015.
(DOCX)

S3 Appendix. Figure A: Selected normalized soil moisture profiles from data sampling to show the change in soil moisture through growing season: May 06–2015 to August 27–2015. The dates are mentioned on top of each figure with mmddyy format.
(DOCX)

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United States Department of Agriculture

The Ecology, History, Ecohydrology, and Management of Pinyon and Juniper Woodlands in the Great Basin and Northern Colorado Plateau of the Western United States

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Abstract

This synthesis reviews current knowledge of pinyon and juniper ecosystems, in both persistent and newly expanded woodlands, for managers, researchers, and the interested public. We draw from a large volume of research papers to centralize information on these semiarid woodlands. The first section includes a general description of both the Great Basin and northern Colorado Plateau. The ecology section covers woodland and species life histories, biology, and ecology and includes a detailed discussion of climate and the potential consequences of climate change specific to the Great Basin and Colorado Plateau. The history section discusses 20,000 years of woodland dynamics and geographic differences among woodland disturbance regimes and resilience. The ecohydrology section discusses hydrologic processes in woodlands that influence soil conservation and loss; water capture, storage, and release; and the effect that woodland structure and composition have on these processes. The final section, restoration and management, covers the history of woodland management, the different methods used, the advantages and disadvantages of different vegetation treatments, and posttreatment vegetation responses. We also discuss successes and failures and key components that determine project outcomes important for consideration when restoring ecosystem function, integrity, and resilience.

Keywords: pinyon, juniper, synthesis, hydrology, topography, soils, life history, taxonomy, seedling ecology, insects, disease, woodland overstory, woodland understory, plant succession, species diversity, competition, soil nutrients, climate change, persistence, migration, woodland infill, patterns, disturbance effects, treatment effects, chaining, windrowing, dozing, shredding, cutting, pesticide use, chemical treatment, fire regimes, evapotranspiration, hydrophobic soils, prescribed fire, restoration

Cover image—Singleleaf pinyon arrived in the very north end of Owens Valley at the base of the White Mountains near the California and Nevada border around 9,000 years ago. It slowly moved north along the east slope of the Sierras arriving to its northwestern most boundary near Pyramid Lake 300 years ago. (Photo from the Benton Range looking towards the woodland belt on the north end of the White Mountains; by Rick Miller.)

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INTRODUCTION

In 1879, John Muir traveled across the rugged young State of Nevada and wrote, "The lower ranges and the foothills and slopes of the higher [mountains] are roughened with small scrubby junipers and nut pines ... Nearly every mountain in the State is planted with it from near the base to a height of from 8 thousand to 9 thousand feet above the sea." The woodlands of scrubby juniper and pine that Muir wrote about are a major component of the Great Basin and Colorado Plateau, shifting in abundance and distribution over thousands of years (fig. 1-1).

Semiarid woodlands, composed of pinyon and/or juniper trees, cover many square miles of the Great Basin and northern Colorado Plateau. Extending across 9 level III ecoregions (fig. 1-2; USDA Forest Service 2018) and 15 Major Land Resource Areas (MLRAs) (fig. 1-3; table 1-1), this vast area is characterized by a complex set of landscapes where climate, geology, soils, and topography vary at multiple scales—resulting in continual changes in potential vegetation, disturbance regimes, resilience, and resistance to invasive annuals (see Glossary for definitions). These semiarid woodlands are typically dominated by a single pinyon or juniper species—or a combination of both—with species composition determined largely by the abundance and distribution of precipitation (winter versus summer), temperature, and soils.

Figure 1-1—When John Muir traveled across Nevada in 1879, he observed scrubby junipers and nut pines occupying the lower slopes and foothills of higher mountains. Since Muir's travels, there has been considerable debate as to the extent of infill and expansion of these woodlands across the Great Basin and Colorado Plateau—a topic thoroughly discussed in this synthesis. Northern Great Basin. (Photo by Rick Miller, Oregon State University.)

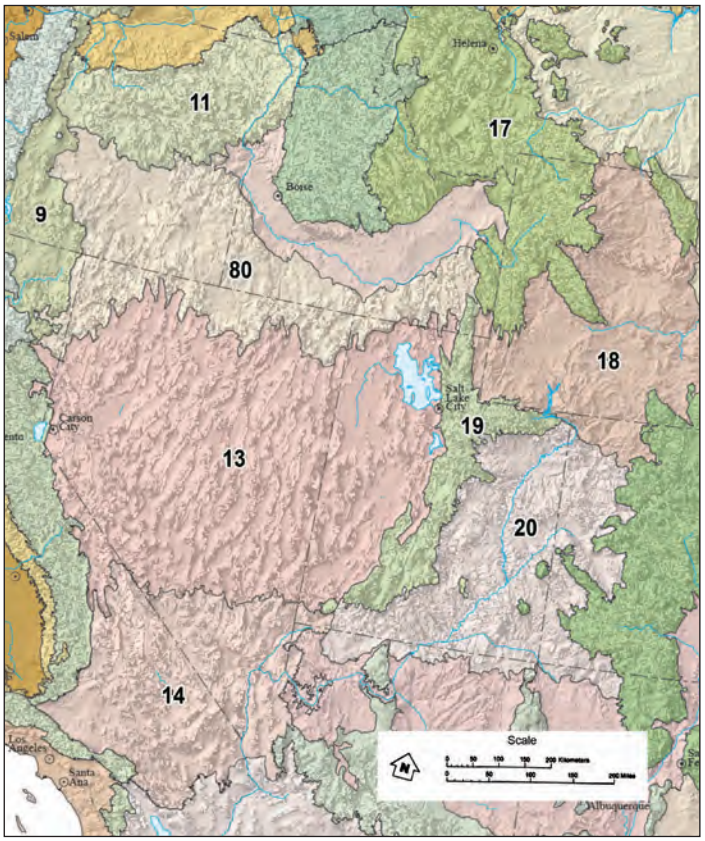

Figure 1-2—This synthesis covers pinyon and juniper woodlands across 9 level III ecoregions, which included parts or all of the Eastern Cascade slopes (#9), Blue Mountains (#11), Central Basin and Range (#13), mountains of the Mojave Basin and Range (#14), southwest end of the Middle Rockies (#17), mountains of the Wyoming Basin (#18), Wasatch and Uinta Mountains (#19), Colorado Plateau (#20), and Northern Basin and Range (#80) (USDA Forest Service 2018).

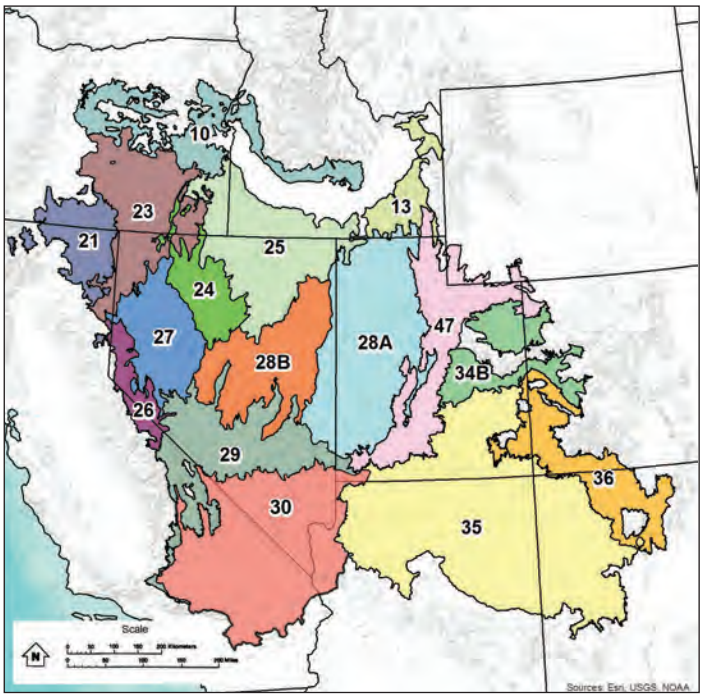

Figure 1-3—Major Land Resource Areas (MLRAs) within the geographic boundaries of this synthesis extend across the ranges of both western juniper and Utah juniper: Central Rocky and Blue Mountain Foothills (#10), Eastern Idaho Plateaus (#13), Klamath and Shasta Valleys and Basins (#21), Malheur High Plateau (#23), Humboldt Area (#24), Owyhee High Plateau (#25), Carson Basin and Mountains (#26), Fallon-Lovelock Area (#27), Great Salt Lake Area (#28A), Central Nevada Basin and Range (#28B), Southern Nevada Basin and Range (#29), Mojave Desert (#30), Warm Central Desert Basins and Plateaus (#34B), Colorado Plateau (#35), the northern Southwestern Plateaus, Mesas, and Foothills (#36), and Wasatch and Uinta Mountains (#47). (Map by Dave Nagel, USDA NRCS 2006).

Table 1-1—Major Land Resource Area (MLRA) names and identification numbers (see map fig. 1-3) included in this synthesis. For each MLRA the size of land area, States listed in descending order of proportion of area it covers, most common elevation range (extreme), geology, common soil orders, range of average annual precipitation (extremes), range in temperatures, and soil temperature regime are described. The synthesis only covers the sagebrush, and pinyon and juniper communities, within these MLRAs. MLRAs 8, 10, and 11 are located in the Northwestern Wheat and Range Region. The remaining MLRAs are located in the Western Range and Irrigated Region. (Descriptions derived from USDA NRCS 2011; and Shane Green, Randy Lewis, and Sara Quitzberg, Soil Scientists, USDA NRCS, Salt Lake City, Utah, personal communication, 2015.)

MLRA (id #)	Area (mi²)	States	Elevation ft	Geology	Soils	PPT inches	Temp °F	Soil moisture	Soil temp
Blue Mt Foothills (10)	17,515	OR ID	1,300–6,600	Basalt alluvium sedimentary	Mollisols Aridisols	8–16 (41)	36–53	Aridic-xeric	Mesic frigid cryic
Eastern Idaho Plateaus (13)	7,270	ID	4,500–6,600 plateaus/foothills 6,600–9,500 mts	Loess underlain by sedimentary & some basalt	Mollisols	12–25 (48)	36–48	Xeric	Frigid Cryic
Klamath Valleys (21)	11,495	CA OR	2,600–4,600 (> 7,000)	Basalt rhyolite andesite	Mollisols	12–30 (9; 30–58)	39–52	Xeric	Mesic frigid (cryic)
Malheur High Plateau (23)	22,896	OR NV CA	3,900–6,900 (> 9,000)	Basalt & andesite	Aridisols & Mollisols	6–12 (> 50)	39–52	Aridic-xeric	Mesic frigid, cryic
Humboldt Area (24)	12,680	NV OR	3,950–5,900 (> 8,850)	Alluvium (some andesite & basalt)	Entisols Inceptisols Mollisols	6–12 (40)	38–53	Aridic	Mesic (frigid)
Owyhee High Plateau (25)	28,930	NV ID OR UT	3,000–7,550 (> 9,800)	Andesite basalt rhyolite	Aridisols Mollisols	7-16 (> 50)	35-53	Aridic-xeric	Mesic frigid
Carson Basin & Mts (26)	6,520	NV CA	3,900–6,550 (13,100)	Granitic andesite basalt	Aridisols Mollisols	5–36	37–54	Aridic-xeric	Mesic (frigid & cryic)
Fallon-Lovelock (27)	12,565	NV CA	3,300–5,900 (< 7,800)	Alluvium andesite basalt	Aridisols Entisols	5–10 (19)	43–54	Aridic	Mesic
Great Salt Lake (28A)	36,775	UT NV ID	4,900–6,550 basin 6,550–11,900 mts	Carbonate (north) andesite basalt (south) Alluvium & lakebed deposits	Aridisols Entisols Mollisols	5–12 (basins) 8–36 (mountains)	34–52	Aridic-xeric (ustic)	Mesic Frigid (cryic)
Central NV Basin & Range (28B)	23,555	NV	3,950–6,560 basin 6,560–11,150 mts	Playa lakebed deposits, old-sedimentary	Aridisols Entisols Mollisols	5–12 (49)	39–53	Aridic-xeric	Mesic frigid, cryic
Southern Nevada Basin and Range (29)	26,295	NV CA UT	1,950–5,600 valleys 9,400 mts	Andesite basalt alluvium	Aridisols Entisols Mollisols mt	3–12 (12–29)	28–72	Aridic-xeric	Mesic
Mojave Desert (30)		CA NV AZ UT	-282–3,950	Alluvium granitic igneous	Aridisols Entisols	2–8 (> 37)	43–76	Aridic	Thermic
Warm Central Desert Basins (34B)	12,850	UT CO	4,100–7,500	Shale sandstone Residual basin floor materials	Aridisols Entisols (Mollisols)	6–10	41–54	Aridic	Mesic
Colorado Plateau (35)	71,735	AZ UT NM CO	4,250–8,000 (> 10,000)	Shale sandstone limestone dolomite volcanic	Alfisols Aridisols Entisols Mollisols	6–18 (< 5–30)	36–66	Aridic or ustic	Mesic frigid
Southwestern Plateaus, Mesas, and Foothills (36)	23,885	CO UT (excluding NM)	4,600–8,500 (> 9,000)	Sedimentary shale sandstone	Alfisols, Inceptisols, Mollisols, Entisols, Aridisols	12–20 (8–31)	37–56	Ustic-aridic	Mesic frigid
Wasatch and Uinta Mts (47)	23,825	UT WY CO ID	4,900–13,500	Volcanic	Aridisols Entisols Inceptisols Mollisols	15–30 (6–10 basins, 10–15 foothills)	30–58	Aridic-xeric-ustic	Frigid (mesic & cryic)

In addition to spatial variation, woodland complexity also varies with time. Significant fluctuations in woodland expansion, contraction, and infill, in addition to changes in structure and composition, have been occurring for tens of thousands of years. However, recent changes attributed to the interaction of natural factors—such as climate with more recent anthropogenic variables—can be difficult to sort out. Twentieth century increases in tree densities (infill) and expansion have resulted in both land management concerns and considerable debate as to the extent of increase, and the primary factors causing these changes. There is also considerable concern about the recent regional die-offs of pinyon and juniper and the consequences of climate change and invasive weedy species to the future of these ecosystems. Managers, private landowners, and scientists struggle with concerns over fire severity and frequency of occurrence, reductions in understory vegetation and forage, changes in wildlife habitat (especially for sagebrush obligates), reduced resistance to invasive species, altered ecohydrology processes, and the reduction in resilience and ecosystem function. As a result, private landowners and public agencies have treated large areas across the Interior West since World War II by removing trees with prescribed fire and/or mechanical and chemical methods.

But tree removal is not always successful for solving the above concerns. Successional trajectories following tree-removal projects have ranged from progression toward native shrub-steppe or shrubland sagebrush communities to large increases in invasive annuals (Miller et al. 2013). And restoration efforts through tree removal have not always separated young postsettlement woodlands from persistent old-growth woodlands. Successful management of pinyon and juniper woodlands requires an ecosystems approach with careful evaluation of restoring ecosystem integrity, function, and resilience (Benson 2012; Boyd et al. 2014; Miller et al. 2017). This necessitates the careful consideration of key ecosystem components in both persistent and newly expanded woodlands that influence ecological function, resilience, and resistance to invasive plant species.

Many dedicated scientists and managers have worked to understand these woodlands in an attempt to provide ecosystem services (including clean air and water, forage, wildlife habitat, and recreation) and to restore ecosystem function. Over the past 75 years we have learned a considerable amount about these woodlands, with many successes and failures. In this synthesis, we have collected and summarized the literature on the ecology, history, and management of these semiarid woodlands in an effort to help managers quickly reference the current state of our knowledge.

Synthesis Purpose and Structure

The primary purpose of this synthesis is to: (1) review the current knowledge of pinyon and juniper ecosystems, in both persistent and newly expanded woodlands; (2) address the issues and concerns regarding pinyon and juniper expansion and treatment effects on ecosystem function and resilience and ecosystem services; and (3) make the scientific information for understanding and managing pinyon and juniper woodlands available to managers, researchers, and an interested public. This document provides a resource of information that draws from a large volume of research papers and reports on these semiarid woodlands. In the synthesis, we have reviewed and cited approximately 1,000 papers (of approximately 2,000) related to pinyon and juniper woodlands in the American West.

The synthesis is divided into five sections. The first section, ***General Physical Setting,*** includes descriptions of both the Great Basin and northern Colorado Plateau. The second section, ***Ecology, Life History, and Biology,*** covers woodland and species life histories, biology, and ecology. This section also includes a detailed discussion of climate and

the potential consequences of climate change specific to the Great Basin and Colorado Plateau, and to the possible future of woodland ecosystems. The third section, ***20,000 Years of Woodland History***, discusses 20,000 years of woodland dynamics, beginning at Glacial Maximum. This section discusses the magnitude of changes of woodland distribution and structure and the primary factors attributed to prehistoric woodland dynamics. The end of this section focuses on recent changes (including the past 200-300 years) related to the interactions between climate and anthropogenic disturbance, the extent of the change, and the geographic differences among woodland disturbance regimes and resilience. Section 4, ***Ecohydrology of Pinyon and Juniper Woodlands,*** discusses hydrologic processes in woodlands that influence soil conservation and loss; water capture, storage, and release; and the effects woodland structure and composition have on these processes. Section 5, ***Restoration and Management,*** covers the history of woodland management, the different methods used, the advantages and disadvantages of different vegetation treatments, and posttreatment vegetation responses. In the ***Conclusion*** we discuss successes and failures and the key components that determine project outcomes important for consideration when restoring ecosystem function, integrity, and resilience.

Geographic and Ecological Boundaries of This Synthesis

Given the large amount of variation that characterizes pinyon and juniper woodlands in the American West, we focus this synthesis on four juniper and two pinyon species that occur in the Great Basin and northern portion of the Colorado Plateau (northern Arizona, eastern Utah, and western Colorado, level III ecoregion 20) (fig. 1-2). Tree species are western juniper (*Juniperus occidentalis* Hook.), Utah juniper (*J. osteosperma* (Torr.) Little), Rocky Mountain juniper (*J. scopulorum* Sarg.), Sierra juniper (*J. grandis* R.P. Adams), singleleaf pinyon (*Pinus monophylla* Torr. & Frém.), and twoneedle pinyon (*P. edulis* Engelm.) where it is primarily associated with Utah juniper. There is considerably less information on Rocky Mountain and Sierra junipers compared to the other four tree species. This synthesis does not extensively cover tree species on the outer perimeter of this region, which include oneseed juniper (*J. monosperma* (Engelm.) Sarg.), alligator juniper (*J. deppeana* Steud.), or California juniper (*J. californica* Carriére). However, some of the research conducted on these species was included to strengthen the discussion on process and function.

Most of this region typically receives less than 35 percent of its total precipitation during the summer. Cool season grasses dominate the majority of the area with warm season grasses becoming codominate in the southern part as summer precipitation increases (Romme et al. 2009; Shane Green, Soil Scientist, USDA NRCS, Salt Lake City, Utah, personal communication, 2017). Although the focus is on the Great Basin and Colorado Plateau, there are portions of several adjacent areas that were included to cover the distribution range of western and Utah juniper (fig. 1-3). The geographic boundaries we include extend north to eastern Oregon and southern Idaho, west along the east slopes of the Cascades and Sierra Nevada Mountains in California, east to the Rocky Mountains in western Colorado and central Wyoming, and south into northern Arizona and the northwestern corner of New Mexico. Ecoregions included are the Eastern Cascade Slopes (9), Blue Mountain (11), Central Basin and Range (13), high elevation mountains of the Mojave (14), southwest corner of the Middle Rocky Mountains (17), Wyoming Basin (18), Wasatch Uinta Mountains (19), northern Colorado Plateau (20), and Northern Basin and Range (80) (table 1-1; fig. 1-2). Major Land Resource Areas included are shown and listed in figure 1-3 and table 1-1.

SECTION 1: GENERAL PHYSICAL SETTING: GEOLOGY, TOPOGRAPHY, AND SOILS

The Great Basin is characterized by basins, mountains, and plateaus that range in elevation from 1,300 feet to more than 10,000 feet—the majority lying between 2,500 and 7,500 feet above sea level (USDA NRCS 2011). Mountain ranges within the Great Basin are commonly 50–75 miles long and 6–15 miles wide (Lustig 1969). Basins, which are located at the lowest elevations, are hot and dry (mesic/aridic, desert shrub) while the higher elevations are cool to cold and moist (frigid to cryic/xeric, mountain shrub or subalpine). Temperature increases approximately 3 °F for every thousand-foot increase in elevation (Oosting 1956). Pinyon and juniper often intermingle with sagebrush on the midslopes between desert and mountain shrub or forest. Alluvium and playa lakebed deposits typically fill the basins (USDA NRCS 2011). Foothills and mountains are commonly composed of volcanic rock (basalt, andesite, and rhyolite) with occasional granitics. Also important are carbonate soils in the central Nevada Basin and Range and sedimentary and carbonate soils in the Great Salt Lake Region formed from Paleozoic sedimentary rocks (table 1-1).

The most common soil orders are Mollisols, Aridisols, and Entisols. The three most common soil temperature regimes are mesic (warm), frigid (cool), and cryic (cold), commonly mapped by elevation and indicator species. Elevations at which these regimes are mapped change with latitude and thus vary with the geographic location of each MLRA. The dominant soil moisture regimes in the Great Basin are dry (aridic, less than 12 inch precipitation zone—"PZ") and moist (xeric, equal to or more than 12 inches PZ), with aridic or xeric bordering on ustic (available summer soil moisture) in the southern end of the Great Salt Lake MLRA (#28A), and Wasatch Mountains MLRA (#47), which form the boundary between the Great Basin and the Colorado Plateau (table 1-1, fig. 1-3). Soils mapped with aridic-xeric (dry-moist) usually fall within the 10– to 12 –inch PZ.

In Utah, the Wasatch Mountains form the boundaries between the Great Basin and the Colorado Plateau. The Colorado Plateau Ecoregion (Level III Ecoregion 20) is characterized by highly dissected intermountain plateaus extending across the eastern half of Utah, the western edge of Colorado, the northern fringe of Arizona, and the northwestern corner of New Mexico. It includes the area drained by the Colorado River and its tributaries—the Green, San Juan, and Little Colorado rivers. Average elevation is 5,000 feet with peaks over 12,000 feet. Common parent materials are shale, sandstone, limestone, dolomite, and volcanic rock outcrop. The most widespread soil orders are Alfisols, Aridisols, Entisols, and Mollisols (USDA NRCS 2011; table 1-1). Soil moisture regimes are commonly ustic, ustic-bordering-on-aridic, or xeric.

Climate

Most of the Great Basin is characterized by a semiarid temperate climate with cold-wet winters, wet springs, and warm and dry summers. Amounts of summer precipitation are low (typically less than 25 percent of total annual precipitation), increasing along a gradient moving south and east from eastern Oregon (less than 5 percent) to the west slopes of the Wasatch Mountains in southcentral Utah (less than 25 percent). Annual precipitation across the region ranges from 6–12 inches at the lower- to mid-elevations and 12–16 inches at the mid- to upper-elevations, with extremes of less than 6 inches in some of the arid basins and more than 20 inches in the higher mountain elevations.

Average annual precipitation across most of the Colorado Plateau is from 6–18 inches, dropping to less than 5 inches in a few desert basins and reaching the highest levels of precipitation of 30 inches in the isolated mountains of southern Utah (USDA

NRCS 2011). Summer precipitation, July through September, accounts for 25–55 percent of total annual precipitation, increasing from the Wasatch Mountains to southeast New Mexico (Romme et al. 2009). April, May, and June are the driest months (USDA NRCS 2011). The Wasatch Mountains, forming the northwest boundary of the Colorado Plateau, receive considerable winter Pacific moisture but weaken the moisture flow to the east resulting in considerably lower winter precipitation and a higher ratio of summer to winter moisture in the basins to the east (Gray et al. 2004).

The modern climate of western North America is influenced predominantly by juxtaposition of eastern Pacific subtropical high, and the southwestern monsoonal circulation for the Gulf of California and Gulf of Mexico, each with spatially and seasonally varying impacts on the region (Bryson and Hare 1974; Mitchell 1976). Monsoons of western North America occur July through September centered over the Sierra Madre Occidental, Sinaloa Durango, Sonora, and Chihuahua (northern and western Mexico). These rains are a result of a shift in wind patterns in the summer as Mexico and the southwest United States warm under intense solar heating. These winds flow from ocean areas into arid and semiarid regions of the Southwest. Arizona, Utah, and southern Nevada and California are primarily influenced by pulses of moisture from the Gulf of California and the Pacific. The seasonal moisture gradient within the area of interest of this synthesis ranges from less than 15 percent to approximately 35 percent of total annual precipitation received during the summer months. This approximates the distributions of Utah and western junipers.

Locally, temperature and the abundance and seasonal distribution of precipitation are strongly influenced by elevation and latitude across both the Great Basin and Colorado Plateau. For every thousand feet increase in elevation, temperature declines approximately 3 °F (Oosting 1956). In central Utah, precipitation increases approximately 5 inches for each thousand-foot increase in elevation (Lull and Ellison 1950). For more detail on climate and climate change, see Section 2 on climate.

Floristics Divisions and Vegetation Zones

The strong latitudinal gradient in Pacific versus Monsoonal moisture resulting in the amounts of precipitation received during the summer months is a major influence in the geographic distribution of plant species (Blaisdell 1958; Davis 2004; Krebs 1972; Oosting 1956). At the regional and local levels, topography and soils are important modifiers of macro climate and moisture availability that determine vegetation composition and structure.

Floristic Divisions

Cronquist et al. (1972) described four floristic divisions of the Intermountain West: (1) Great Basin, (2) Wasatch Mountains, (3) Colorado Plateau, and (4) Uinta Mountains. Floristic divisions were further divided into 16 floristic provinces. Division boundaries are partially influenced by local regions of endemic species and community dominance plus climatic differences, physical differences, and/or soil differences. At this scale, climatic differences are largely influenced by elevation and latitude.

Vegetation Zones

Vegetation zones are an area in which a particular type of vegetation is expected to dominate over time, commonly referred to as the climax or potential vegetation. Vegetation zones within the Intermountain West are closely associated with elevation, which changes with latitude and aspect. Much of the paleobotany literature refers to the vegetation zones listed below, which include characteristic plant species (Appendix A; Thompson 1990).

Common vegetation zones and their diagnostic species (see Appendix A for a complete list of common and scientific plant names) in the Great Basin and Colorado Plateau associated with pinyon and juniper woodlands in the Intermountain Region include:

1a. Desert shrub—less than 6 inches PZ on nonsodic or nonsalty soils. Spiny hopsage, winterfat, bud sagebrush, shadscale, Nuttall's saltbush, Indian ricegrass, James' galleta, and bottlebrush squirreltail.

1b. Desert shrub (salt-desert shrub)—less than 8 inches PZ on salty or sodic soils (typically in the bottoms of ancient pluvial lakes). Greasewood, salt rabbitbrush, shadscale, basin wildrye, saltgrass, alkali cordgrass, and alkali sacaton.

2. Sagebrush—semi-desert, 8–12 inches PZ. Wyoming big sagebrush, basin big sagebrush, low sagebrush (shallow or clayey sub-soils), black sagebrush (shallow to an indurated duripan), rubber (gray) and green rabbitbrush, bitterbrush, bluebunch wheatgrass (only on north aspects in the southern portion of the region), Sandberg bluegrass, muttongrass, Thurber's needlegrass, needle and thread grass, Indian ricegrass, and blue grama and galleta on aridic soils bordering on ustic.

3. Upland sagebrush and pinyon and juniper—12–16 inches PZ. Mountain big sagebrush, low sagebrush, bitterbrush, western juniper, Utah juniper, singleleaf and twoneedle pinyon, Idaho fescue, bluebunch wheatgrass, Thurber's needlegrass, Columbia needlegrass, Lettermen's needlegrass, western needlegrass, pine needlegrass, Junegrass, Sandberg bluegrass, and low elevation aspen (north-facing snow drift pockets).

4. Mountain brush—more than 16 inches PZ. Mountain big sagebrush, bitterbrush, snowberry, serviceberry, curlleaf mountain mahogany, Idaho fescue, red fescue, spike fescue, Columbia needlegrass, Lettermen's needlegrass, western needlegrass, Lemmon's needlegrass, mountain brome, June grass and mutton grass; on the Wasatch and Colorado Plateau, Gambel oak and bigtooth maple frequently occur in place of the sagebrush-mountain brush zone.

5. Mixed conifer forest—more than 20 inches PZ. Douglas-fir, whitebark pine, limber pine, ponderosa pine, lodgepole pine, white fir, grand fir, aspen, Sierra juniper, and bristlecone pine.

6. Subalpine woodlands—usually composed of bristlecone, limber or whitebark pine, and occasionally Engelmann spruce located just below the limit of tree growth (timberline) and above the foothill or montane or mixed conifer zone.

SECTION 2: ECOLOGY, LIFE HISTORY, AND BIOLOGY

Summary

Pinyon and juniper woodlands occupy over 70,000 square miles of the Great Basin and Colorado Plateau, extending across a significant climatic gradient from eastern Oregon to the Four Corners of Utah, Colorado, Arizona, and New Mexico (West 1984). These semiarid woodlands occupy precipitation zones between 8 and 20 inches, elevations of less than 1,000 to over 8,000 feet, and a wide variety of soils and parent materials. Pinyon and juniper woodlands often project the illusion of being homogeneous, but they vary in age, structure, and composition, and they often intermingle with other plant communities. The broad heterogeneity of these woodlands and the sites they occupy result in large spatial and temporal variations in ecohydrologic process, disturbance regimes, resilience to disturbance, response to vegetation

management, and resistance to invasive species (Stringham et al. 2015; West 1999; West et al. 1978b). The most common semiarid conifer species in this region of the western United States are Utah juniper (*Juniperus osteosperma* (Torr.) Little), western juniper (*J. occidentalis* Hook.), singleleaf pinyon (*Pinus monophylla* var. *monophylla* Torr. & Frém), and twoneedle pinyon (*Pinus edulis* Engelm.). Common but less abundant within this region are Rocky Mountain (*Juniperus scopulorum* Sargent, Gard. & Forest) and Sierra junipers (*Juniperus grandis* R.P. Adams).

Temperature and amount and seasonal patterns of moisture are the primary variables that determine the distribution of these semiarid conifers and their varieties. Rapid warming periods interrupted by cold periods during late winter and early spring in the Northwest limit the northwestern distributions of Utah and singleleaf pinyon. Of the four species, Utah juniper is the most adapted to drought (West 1984). Western juniper typically occurs in cooler, and somewhat wetter environments than Utah juniper. And, the two pinyons are separated by the amounts of summer precipitation. Pinyon and juniper woodlands occupy a wide variety of soils, but there are some general differences in soil characteristics that occur between postsettlement and persistent woodlands.

Soils occupied by persistent woodlands are most commonly associated with shallow to restrictive layers including claypans, fractured basalt, and calcareous horizons and extremely cobbly, or very coarse-textured with gravelly surfaces, often resulting in shallow and transient soil moisture storage (Campbell 2015; Leonard et al. 1987). Woodlands found on deeper and more productive soils (often with higher levels of organic matter) are mostly relatively young and were previously occupied by shrubland or grassland communities.

Annual cone and seed development for the four conifer species is highly variable both temporally and spatially, and it requires at least two growing seasons to produce mature seed (Chambers et al. 1999a). Pinyon pines have short-lived seeds and junipers relatively long, affecting the longevity and abundance of seed in the seedbank. In singleleaf pinyon, a typical mean seed crop during a year of heavy cone production ranges from 2,000 to 8,000 filled seeds per tree, but values for individual trees vary tremendously. Pinyon and juniper seeds are well adapted for dispersal by both birds and small mammals, with distances commonly ranging from several feet to several miles. Germination and establishment are most likely to occur when favorable growing season conditions follow a mast (cone producing) year. Placement of seed beneath nurse plants (shrubs) or covered by soil such as a seed cache also increases the chances of successful establishment. Competition from forbs and grasses can reduce seedling emergence, but once established, competition appears to have little effect on survival.

Pinyon and juniper species are hosts to a large number of insects, disease, and fungi (Bunderson et al. 1986; Shaw et al. 2005). All three can cause reductions in seed crops and increase susceptibility to other pests and mortality. Insects are the largest cause of mortality, with ips (bark beetle) considered the most important insect mortality agent in the Colorado Plateau. Drought is closely linked to pest outbreaks and can significantly increase mortality, especially in the Colorado Plateau.

Expansion of woodlands into sagebrush ecosystems is characterized by an inverse relationship of an increasing tree overstory and decreasing shrub and herbaceous understory (Margolis 2014; Miller et al. 2008; Roundy et al. 2014a). The time it takes woodlands to go from the very early to late successional stages (Phase I to Phase III) is largely determined by the key components of the ecological site and disturbance history. The shift from sagebrush-dominated ecosystems to woodland influences water, energy, and nutrient cycles; C and N pools; and disturbance regimes, wildlife habitat, resilience, and resistance to invasive species.

The earth's climate has been continually changing, long before the formation of the first pinyon and juniper woodland, and has had significant impact on woodland distribution, migration, expansion, contraction, infill, composition, structure, resilience, and resistance to invasive species. But recent concerns over natural climatic variation linked to anthropogenic effects on climate have raised considerable apprehension related to future impacts on ecosystems in the West including pinyon and juniper woodlands (Eddy and Bradley 1991). Increasing temperatures and changes in the amounts and seasonal distribution of precipitation will have significant impacts on persistence and migration of woodlands, insect and disease outbreaks, wildfire, and the expansion of invasive annual grasses. These impacts will likely vary regionally and at multiple scales across the Great Basin and Colorado Plateau.

Woodland Distribution and Ecological Site Characteristics

Pinyon and juniper woodlands occupy 33 to 100 million acres in the American West (West 1984). The inconsistency in area reported is largely a result of the method used to estimate area, the geographic area or species included, and the criteria used to define persistent pinyon and juniper woodlands, wooded shrublands, newly expanding woodlands, and pinyon and juniper savannas (see Glossary for definitions). Kuchler's (1970) potential vegetation map estimates 43 million acres of pinyon and juniper woodlands across Nevada, Utah, Colorado, Arizona, New Mexico, and a portion of southeastern California. West (1984) reported 60 million acres, which includes Kuchler's estimates in addition to adding the Trans-Pecos region of west Texas and western juniper in the northwest. Within the boundaries of this synthesis—the Great Basin and northern Colorado Plateau—there is an estimated 48 million acres of woodland (table 2-1; figs. 2-1, 2-2).

Table 2-1—Estimated area occupied by Utah and western junipers and singleleaf and twoneedle pinyon pines in the Intermountain West (from Miller and Tausch 2001).

State	Species	Area (acres)	Reference
Arizona	JUOS-Pinyon	11,641,999	Springfield 1976
California	JUOC	1,283,999	Bolsinger 1989
	JUOC savanna	796,999	Bolsinger 1989
	JUOS-JUCA	1,089,000	Bolsinger 1989
Colorado	JUOS-PIED	5,937,880	estimated from Powell et al. 1994
Idaho	JUOC	617,500	Chojnacky 1995
	JUOS	137,001	Tueller et al. 1979
New Mexico	JUOS-PIED	3,081,999	Springfield 1976
Nevada	JUOS-PIMO	7,155,970	O'Brien and Woudenberg 1999
	JUOS	1,683,566	O'Brien and Woudenberg 1999
	JUOC	100,000	estimated Miller et al. 2005
Oregon	JUOC	3,339,000	Azuma et al. 2005
	JUOC savanna	3,227,000	Azuma et al. 2005
Utah	JUOS-PIED (PIMO)	7,766,307	O'Brien and Woudenberg 1999
	JUOS	148,400	O'Brien and Woudenberg 1999
Wyoming	JUOS-PIED	202,999	Powell et al. 1994
Total		**48,209,619**	

JUOS = *Juniperus osteosperma;* JUOC = *J. occidentalis* var. *occidentalis,* JUCA = *J. californica,* PIMO = *Pinus monophylla,* PIED= *P. edulis*

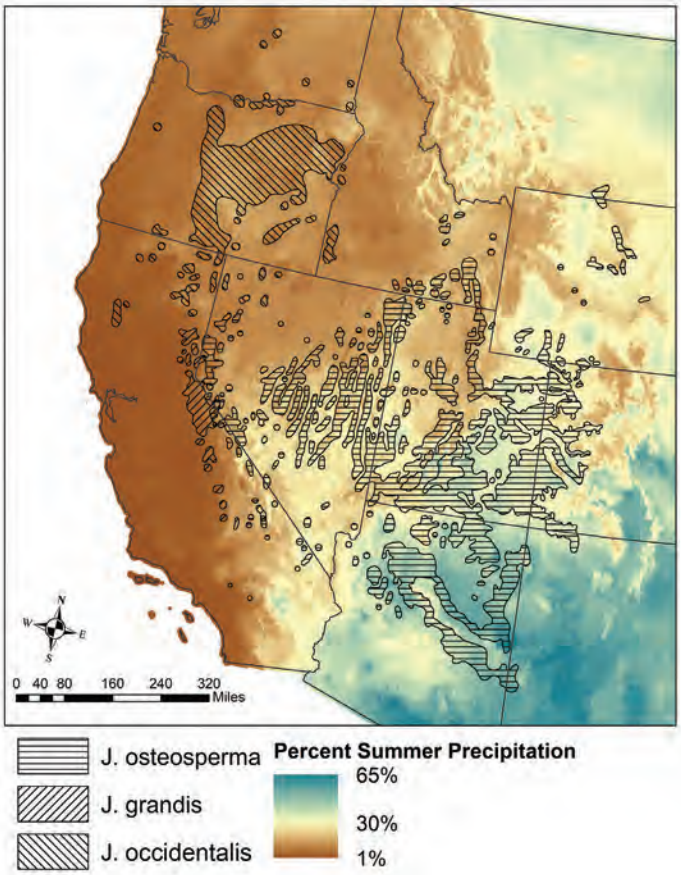

Figure 2-1—Distribution of Utah (*Juniperus osteosperma*), western (*J. occidentalis*), and Sierra (*J. grandis*) junipers across a monsoonal precipitation gradient in the Great Basin and Colorado Plateau. Map derived by David Board, Ecologist/Data Analyst, USDA Forest Service, Rocky Mountain Research Station, Reno, NV.

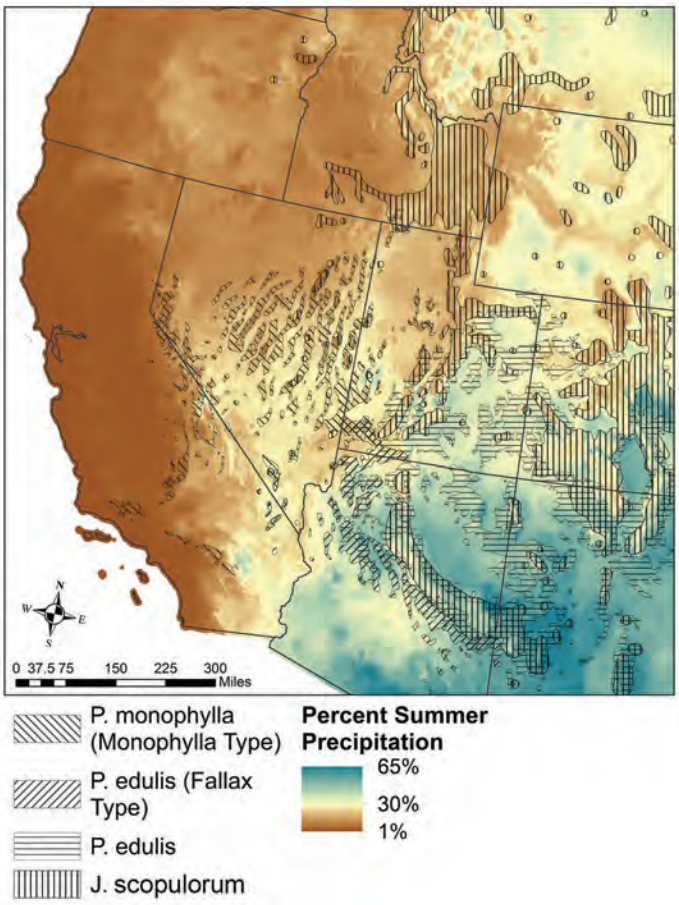

Figure 2-2—Distribution of singleleaf (*Pinus monophylla*) pinyon, twoneedle (*P. edulis*) pinyon, variety P. edulis var. fallax, and Rocky Mountain juniper (*J. scopulorum*) across a monsoonal precipitation gradient in the Great Basin and Colorado Plateau. Map derived by David Board, Ecologist/Data Analyst, USDA Forest Service, Rocky Mountain Research Station, Reno, NV.

Figure 2-3—Pinyon and juniper woodlands may appear as homogenous stands within a contiguous elevation belt. But in reality, they vary in stand structure and composition and intermingle with other plant communities across continually varying topography, soils, and microclimates. Schell Creek Mountains, Nevada. (Photo by Rick Miller, Oregon State University.)

Although pinyon and juniper woodlands are sometimes reported as occurring within a specific elevation belt in the Great Basin, they often intermingle with other plant communities (Tueller et al. 1979). The transition between pinyon and juniper woodlands to other vegetation zones or plant communities is usually associated with changes in elevation, aspect, microtopography, and soils, which influences temperatures, abundance of available moisture, and disturbance regimes (fig. 2-3). Latitude also influences woodland elevation boundaries and dominance on north versus south aspects (Tueller et al. 1979). Pinyon and juniper woodlands typically occupy elevations well above the desert basins in the more than 8 inches PZ and just above the 8 -12 inches PZ occupied by the sagebrush semi-desert. Utah juniper often dominates the lower woodland elevations (typically less than 7,000 feet). Woodlands composed of both pinyon and juniper frequently intermingle with upland sagebrush (10-16 inches PZ) (Stringham 2015a,b; West 1999). Mountain brush and mixed conifer forests frequently occupy elevations just above or intermingle with the upper pinyon and juniper woodland boundary. In the northwest, western juniper is the sole semiarid conifer, which most commonly occurs in the 10–15-inch PZ (Gedney et al. 1999) and is associated with Wyoming big sagebrush at the lower elevations, mountain big sagebrush at the mid- to upper- elevations, and on shallow to very shallow soils low sagebrush (Miller et al. 2005).

Climate

The majority of woodlands receive 10–16 inches of total annual precipitation across the Intermountain Region (Stringham et al. 2015; West et al. 1978a; West 1988), with extremes ranging from 8 to 20 inches (Stringham et al. 2015). There is a large range in the distribution of seasonal precipitation along a gradient from eastern Oregon to southeast Utah and southwest Colorado, where summer precipitation ranges from less

than 5 percent to more than 30 percent of the total annual precipitation (figs. 2-1, 2-2). This northwest to southeast shift in the seasonal precipitation is a result of the importance of Pacific and Monsoonal storm systems.

The quantity and seasonal availability of soil moisture, especially in the summer, are major factors influencing the geographic distribution of plant species across the Intermountain Region (Blaisdell 1958; Daubenmire 1974; Oosting 1956). Juniper is generally more tolerant to dry and cold conditions (especially fluctuations of cold and warm in early spring) than pinyon, resulting in juniper often dominating the more arid lower elevations of the woodland zone and often the more dominant tree in the northern latitudes (Tueller and Clark 1975). The relative abundance of pinyon to juniper often increases with elevation, and pinyon typically becomes dominant on the midslopes, where temperature inversions create thermal belts that have less extreme temperatures than the basins below (Billings 1954; Tueller et al. 1979; West et al. 1978).

Western juniper and singleleaf pinyon grow in areas where most precipitation falls between October and May (Cole et al. 2008a; Gibson 2011; Miller et al. 2005), while twoneedle pinyon grows in areas where more than 30 percent of precipitation falls between July and September (fig. 4-4 in Section 4; Cole et al. 2008a; West et al. 2007a). Utah juniper grows in both winter-dominant and summer-dominant precipitation regimes, although it is more widely distributed where most precipitation falls in winter (Gibson 2011). Seasonal ranges in temperature between these four species are quite similar, but temperature events not captured in monthly climate data can exert control on species distributions.

Singleleaf pinyon and Utah juniper typically grow in thermal belts above the level of freezing fogs in valleys and are susceptible to damage from freezing in late winter and early spring during rapid shifts between warm periods and Pacific, or polar, front cold periods (Billings 1954; Nowak et al. 1994). The northwestern limits of singleleaf pinyon and Utah juniper appear to correspond to the energy limits of cold Pacific fronts resulting in rapid cycling of warming periods interrupted by cold periods during late winter and early spring brought about by these Pacific frontal storms (Nowak et al. 1994a; West et al. 1978a). These warm periods encourage pinyon to break dormancy early, making them susceptible to frost damage. Western juniper is limited at upper elevations by extreme winter temperatures and may be limited by spring freezes at lower elevations (Miller and Rose 1995; Miller et al. 2005). Twoneedle pinyon is sensitive to soil temperature in the upper soil layer during summer, especially during drought (West et al. 2007a; Williams and Ehleringer 2000).

Of the four species, Utah juniper is the most adapted to drought (Munson et al. 2011). Western juniper typically occurs in cooler, and somewhat wetter environments than Utah juniper (fig. 2-4; Miller et al. 2005; Nowak et al. 1994a) and is more sensitive to drought in sites with high evapotranspiration demand, low soil water storage capacity, or both, such as lower elevations, steep slopes, and rocky or sandy soils (Knutson and Pyke 2008). Utah juniper appears to be much less sensitive to changing climate than both pinyon species and western juniper, based on the paleoecological record (Greenwood and Weisberg 2008; Miller et al. 2005; Nowak et al. 1994a). Twoneedle pinyon appears to be the most sensitive to drought of these four species, particularly to drought in summer when temperatures are typically high (Lloret and Kitzberger 2018; Peterman et al. 2013; West et al. 2007a; West et al. 2007b). Singleleaf vulnerability to drought appears to be low in the Great Basin (Biondi and Bradley 2013) compared to high vulnerability of twoneedle pinyon in the Colorado Plateau (Breshears et al. 2005; Mueller et al. 2005a) (discussed in further detail in Sections 2 and 3).

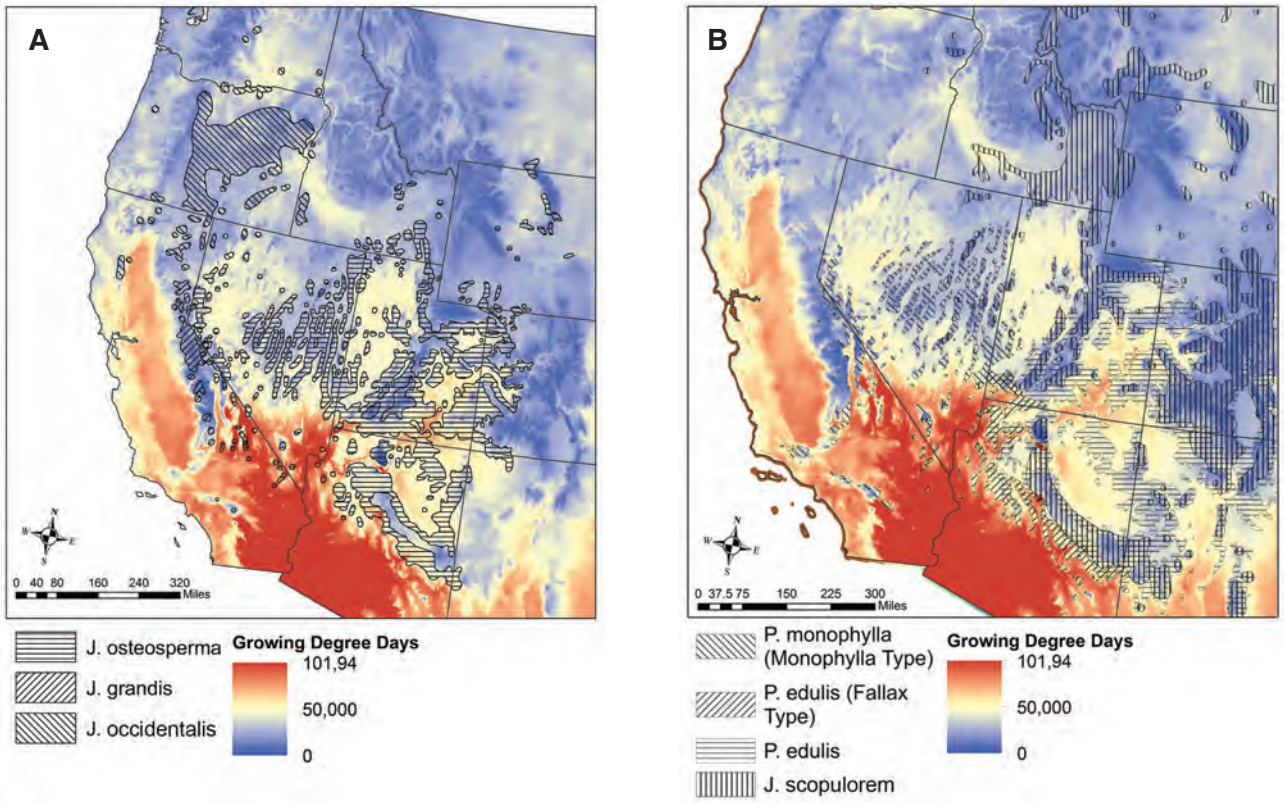

Figure 2-4—Distribution of (A) Utah (*Juniperus osteosperma*), western juniper (*J. occidentalis*), and Sierra juniper (*J. grandis*); and (B) twoneedle pinyon (*Pinus edulis*), type Fallax, singleleaf pinyon (*P. monophylla*), and Rocky Mountain juniper (*Juniperus scopulorum*), across temperature gradients based on Growing Degree Days (GDDs). GDDs are based on 30-year averages with a lower limit of 32 ˚F and an upper limit of 110 ˚F. (Map derived by David Board, Ecologist/Data Analyst, USDA Forest Service, Rocky Mountain Research Station, Reno, NV.)

Soils

> *"The best stands* [of pinyon pine] *are found on coarse gravel, gravelly loam, or on coarse sand, of 1.5 m* [5 feet] *in depth, on which humus and ground cover are almost entirely lacking"* (Phillips 1909).

Pinyon and juniper are capable of growing on a wide range of soils and parent materials across the Great Basin and Colorado Plateau (Harper and Davis 1999; Leonard et al. 1987; Pearson 1931; Springfield 1976; Stringham et al. 2015; West et al. 1998; table 1-1). Trees occupy soils from parent materials originating from metamorphic, sedimentary, and igneous sources including tuff, welded tuff, pumice, volcanic ash, rhyolite, andesite, granite, basalt, limestone, sandstone, eolian soils, and colluvial or alluvial mixtures of the above. Woodlands most commonly occur on Mollisols, Aridisols, Entisols, and to a lesser degree Inceptisols. The highest tree densities are most frequently found on Mollisols, which are typically the most productive among the above soil orders (Nettleton and Mays 2007), and have the highest potential for encroachment (Campbell 2015). Pinyon and juniper woodlands are also found on soils with nearly all particle sizes from fine to coarse—with the exception of silty and sandy skeletal (Leonard et al. 1987). Trees occupy soil depths ranging from very shallow to deep (Barney and Frischknecht 1974; Campbell 2015; Leonard et al. 1987). On very shallow soils, tree roots often penetrate the deep fractures and cracks of the restrictive layers.

The wide variety of soils occupied by pinyon and juniper result in different levels of potential productivity, fuel loads, size and density of trees, and understory composition (Leonard et al. 1987; Miller et al. 2005; Ramsey 2003; Stringham et al. 2015). This

results in changes of woodland structure and disturbance regimes, which can occur at relatively small scales (Miller and Heyerdahl 2008). In northern Arizona, tree densities on limestone- and basalt-derived soils were similar but double that of sandstone soils (Landis and Bailey 2005). On heavy clay or shallow claypan soils, western juniper densities and growth rates are significantly less than on moderately deep clay loams and loams (Miller and Rose 1995; Young and Evans 1981).

Tree mortality can also vary across different soils. Greater dieback in singleleaf pinyon and Utah juniper occurred in Arizona on soils derived from volcanic cinder compared to basalt or sedimentary (Koepke et al. 2010). Geographic information data across the Colorado Plateau demonstrated that 84 percent of the pinyon and juniper mortality during the 2003 and 2004 drought occurred on soils with relatively low available water holding capacity or less than 3.9 inches (Peterman et al. 2013). These are soils that typically have high sand and low organic matter content. Low soil water availability decreases the sapwood/unit leaf area, which increases the sensitivity of trees to bark beetle mortality.

There are some general differences in soil characteristics that occur between postsettlement and persistent woodlands, although there is considerable overlap. Persistent woodlands are often associated with rock outcrops, knolls, ridges, and/or soils that are shallow, coarse, rocky, and often high in clay or sand (fig. 2-5; Barney and Frischknecht 1974; Bauer and Weisberg 2009; Cottam and Stewart 1940; Emerson 1932; Holmes et al. 1986; Miller and Rose 1999; Nicol 1937; Stringham et al. 2015; Woodbury 1947). Characteristics reported in soil surveys most frequently associated with persistent woodlands are shallow to restrictive layers including claypans, fractured basalt, and calcareous horizons and extremely cobbly or very coarse-textured with gravelly surfaces (Leonard et al. 1987; ; Stringham et al. 2015; USDA NRCS 1997; Randy Lewis, Soil Scientist USDA NRCS, Tremonton, Utah, personal communication, 2015).

Figure 2-5—Old-growth woodlands frequently occur on soils of low productivity associated with rock outcrops, knolls, ridges, and/or soils that are shallow to very shallow, coarse, rocky, and often high in clay or sand. But they can also occur on mollic soils. Central Nevada. (Photo by Rick Miller, Oregon State University.)

Romme et al. (2009) reported that persistent woodlands tended to occur where soil moisture storage is shallow and transient. Early work by Emerson (1932) reported pinyons and junipers typically grow on rocky ridges and dissected edges of mesas, whereas grasslands were on the more level areas at the base or on the tops of these mesas. If persistent stands of pinyons and junipers are found on moderately deep to deep soils, the soils are typically skeletal and/or coarse-sandy (Harris et al. 2003; Jacobs et al. 2008; Leonard et al. 1987; Miller and Heyerdahl 2008; Waichler et al. 2001). In relatively dense persistent woodlands, soils typically lack mollic horizons, are poorly developed (Blackburn et al. 2015), and are of low productivity (Barney and Frischknecht 1974; Howell 1941; Leonard et al. 1987; Miller and Heyerdahl 2008; Springfield 1976; Weisberg et al. 2008). However, presettlement woodlands have been reported on relatively productive, moderately deep to deep soils (Floyd et al. 2004). Mollic horizons can also be found in persistent pinyon and juniper woodlands with relatively open canopies supporting a dominant understory of perennial herbaceous vegetation on moderately deep to deep soils with adequate available moisture—e.g., more than 12 inches PZ (fig. 2-6). However, the majority of woodlands found on the deeper and more productive soils are often composed of postsettlement trees (Bauer and Weisberg 2009; Campbell 2015; Emerson 1932; Jacobs et al. 2008; Miller et al. 2005; Miller and Heyerdahl 2008; Nicol 1937; Woodbury 1947). Relatively young woodlands expanding into Mollisols can potentially have the highest tree densities (Nettleton and Mays 2007).

Soil Moisture and Temperature Regimes

Soil moisture regimes that commonly support pinyon and juniper woodlands within the Great Basin and the northern portion of the Colorado Plateau are xeric or intergrades of aridic/xeric (e.g., aridic bordering on xeric, see soil moisture regime in Glossary and

Figure 2-6—This western juniper woodland—with 20 to 25 percent tree canopy cover—grows on moderately deep sandy (pumice) skeletal loam soils with an understory of bluebunch wheatgrass, Idaho fescue, and mountain big sagebrush. The majority of trees are 200–400 years old and 20th century infill has been minimal to moderate. Horse Ridge, Oregon. (Photo by Rick Miller, Oregon State University.)

sidebar 1) and aridic/ustic (Leonard et al. 1987). Soil temperature regimes are typically mesic and frigid. But Rocky Mountain juniper most commonly occurs on frigid/ustic soils. Pinyon and juniper species on thermic, mesic/aridic, and cryic/udic soils are less common (Campbell 2015; USDA NRCS data). Over 50 percent of twoneedle pinyon occupies mesic (warm) and aridic-ustic intergrades, whereas singleleaf pinyon typically grows on mesic and frigid soils that are xeric or aridic-xeric intergrades (table 2-2). Twoneedle and singleleaf pinyons, and Utah and western junipers, typically do not grow on cryic soils, but Sierra juniper commonly grows on cryic soils. Oneseed and alligator junipers, which grow on the southern and southeastern boundaries of Utah juniper, occur on ustic soils where summer precipitation accounts for more than 35 percent of the annual total (figs. 2-1, 2-2).

Potential woodland expansion into sagebrush communities varies across soils, moisture, and temperature regimes (Campbell 2015). Encroachment potential is moderate to high on mesic and frigid soils with xeric soil moisture regimes or xeric and aridic intergrades. The potential for encroachment declines on aridic soils, especially where mean annual precipitation is less than 10 inches, and very low in cryic and thermic temperature regimes, and soils that are poorly drained, alkali, saline, and sodic.

Sidebar 1

Soil Term Reference
(see Glossary for expanded definitions)

Aridic – dry
Xeric – moist
Ustic – summer moisture regime
Mesic – warm
Frigid – cool
Cryic – cold

Topography: Elevation and Landform

The majority of Utah juniper and pinyon woodlands are located between 4,500–8,000 feet (Menlove et al. 2016; Springfield 1976; Woodbury 1947; Wright et al. 1979) and western juniper between 1,500– 6,000 feet (Gedney et al. 1999; Miller and Rose 1995). But elevations occupied by pinyon and juniper woodlands vary with latitude and, at local scales, with aspect. In the White Mountains just east of Bishop, California, woodlands grow between 6,500–9,500 feet (Jennings 1995; St. Andre et al. 1965). At 9,500 feet, they are replaced by limber and bristlecone pines. In the northern range of western juniper along the Columbia River, trees are found at 600 feet (Miller et al. 2005). Another exception is Sierra juniper, which typically grows in open scattered stands with other conifers near the treeline on the east slopes of the Sierra Nevada Mountains (Miller et al. 2005) and at high elevations in the mountains of central and western Nevada above 9,000 feet (Charlet 1996).

Limited moisture is a primary factor restricting woodland movement into lower elevations (Daubenmire 1943; Pearson 1920). But spring temperature inversion layers that form cold-air layers in the valley basins also appear to be related to the lower boundary of pinyon and juniper woodland, with shrubland forming along the base of the slopes and the valley floors (Billings 1954). At the upper elevations, cold temperatures and/or competition from other conifer and mountain shrub species better adapted to the environmental conditions limit pinyon and juniper. Size of the mountain mass can also influence woodland elevation. Woodlands often occur at higher elevations on smaller mountain ranges as they tend to intercept less moisture than larger mountain masses (Tueller et al. 1979; West et al. 1978a).

Woodlands also grow across a broad range of landforms (Romme et al. 2009; Stringham et al. 2015) including ridges, hill and mountain slopes, terraces, tablelands, plateaus, alluvial fans, broad basins, and valley floors. Across the Colorado Plateau it is common to observe woodlands dominating the convex slopes and shrublands in the adjacent concave topography (fig. 2-7).

Table 2-2—Juniper and pinyon species in the American West, their general range, and soil moisture regimes they commonly occupy within the Great Basin and northern Colorado Plateau (from Adams 2014; Bailey 1987; Cole et al. 2008; Critchfield and Little 1966; Eckenwalder 2009; Leonard et al. 1987; Vasek 1966; West 1999; Willson et al. 2008).

Species		Soil temperature - moisture regimes	General range and elevation
Juniperus			
J. arizonica[1]	Redberry juniper		Central and southeastern Arizona to southwestern New Mexico and northern edge of Mexico; 3,200–5,250 (7,200) ft
J. californica	California juniper		Central California, western Arizona and south into Baja; (900) 2,450–3,900 (5,250) ft
J. ashei	Ashe's juniper		Central Texas, Oklahoma, Arkansas
J. coahuilensis[2]	Redberry juniper		Southwestern Texas and northern Mexico 3,940–6,560 ft
J. communis	Common juniper	Frigid-cryic/xeric	var. *depressa* – Alaska, Canada, northeastern U.S., outlying populations central U.S.; var. *kelleyi* Alaska, British Columbia, northwestern U.S.
J. deppeana	Alligator juniper	Mesic-ustic	Southwest and Mexico 4,900–9,500 ft
J. flaccida	Drooping juniper		Mexico; 6,000–8,000 ft
J. grandis[3]	Sierra juniper	Frigid, cryic/xeric, xeric-aridic	Sierras and the San Gabriel, San Bernardino and San Jacinto Mountains, high mts of central Nevada; 3,280–9,850 ft
J. horizontalis	Creeping juniper		Northern U.S.; 0–3,300 ft
J. monosperma	Oneseed juniper	Mesic/udic, ustic, and aridic-ustic	Northern Arizona, New Mexico, southeastern Colorado northern and western Texas; 3,300–7,550 ft
J. occidentalis	Western juniper	Mesic, frigid/xeric, xeric-aridic	Northwest; 600–7,000 ft
J. osteosperma	Utah juniper	Mesic, frigid/xeric, aridic-xeric, aridic-ustic,	Great Basin and Colorado Plateau; 4,250–8,225 ft
J. pinchotii	Pinchot's juniper		western and central Texas, western Oklahoma
J. virginiana	Eastern redcedar		Midwest and eastern U.S.
J. scopulorum	Rocky Mountain juniper	Frigid-ustic (aridic/ustic)	Interior Mountain Ranges from British Columbia to northern Arizona and New Mexico; 5,000–8,500 ft
Pinus (cembroides)			
P. cembroides	Mexican pinyon		Southwestern Texas and Mexico
P. discolor[4]	Border pinyon		Southern Arizona and New Mexico
P. edulis	Twoneedle	Mesic, (frigid)/aridic-ustic	Colorado Plateau, central Colorado, New Mexico; var. Fallax; 4,500–7,500 (8,500) ft
P. monophylla	Singleleaf	Mesic, frigid/xeric, aridic-xeric	Great Basin Nevada, southern California into Baja; var. *monophylla, californiarum;* 4,000–8,000 (10,000 White Mts) ft

[1] Syn: *J. coahuilensis,* which occurs in Mexico and southwest Texas and *J. erythrocarpa.*
[2] Syn with *J. erythrocarpa*
[3] Syn: *J. occidentalis* var. *australis*
[4] Disputed species; some consider to be *P. cembroides* var *bicolor*

Taxonomy

There are 15 species of juniper and 4 species of pinyon in the American West and northern Mexico (table 2-2). However, singleleaf and twoneedle pinyons, and Utah and western junipers, are the primary species occurring within the Great Basin and northern Colorado Plateau. Two additional species are typically found growing in cooler temperatures than western and Utah junipers (fig. 2-4a,b). Rocky Mountain juniper is found primarily in the Rocky Mountains and Mogollon Rim, and Sierra juniper is found

Figure 2-7—Across the Colorado Plateau, it is common to observe woodlands dominating the convex slopes and shrublands in the adjacent concave topography—where soils are usually deeper and surface fuels greater. Northern Arizona. (Photo by Rick Miller, Oregon State University.)

on the upper east slopes of the Sierras and high mountain ranges in central Nevada. Pinyon and Utah juniper species grow separately or in mixed stands, whereas western juniper is not associated with pinyon pines. The abundance and seasonal distribution of precipitation and temperature are primary factors that determine the distribution and separation of these tree species (figs. 2-1, 2-2, 2-4a,b; Springfield 1976).

Utah Juniper (Juniperus osteosperma (Torr.) Little)

Utah juniper is the most common tree in the Great Basin (Lanner 1984) and one of the most abundant trees in the Colorado Plateau. Within the Great Basin, Utah juniper, often associated with singleleaf pinyon, occupies 17 million acres, of which nearly two-thirds occur in Nevada (Tueller et al. 1979). This species is most commonly found from 4,500–8,500 feet in elevation and ranges from western New Mexico and central Wyoming to the east slopes of the Sierra Nevada Mountains (fig. 2-1; tables 2-1, 2-2; Cronquist et al. 1972; Vasek 1966). Its southern boundary occurs in the high mountains of the Mojave and Sonoran deserts in southern California and along the Mogollon Rim in Arizona where it is associated with blackbrush (fig. 2-8). It occurs as far north as southern Montana in the Pryor Mountains (fig. 2-9). The majority of its range is characterized by hot, dry summers and wet, cold winters with precipitation ranging from 10 to 18 inches and extremes as low as 8 and as high as 20 inches. The species extends into north central Arizona and western New Mexico where summer precipitation approaches 40 percent of the total annual precipitation (fig. 2-1). But the majority occurs where summer moisture accounts for less than 30 percent of total annual precipitation. It grows on a wide range of soils, but most commonly on gravelly loams and gravelly clay loams within a pH range of 7.4 to 8.0. It most often occupies soils with aridic and xeric soil moisture regimes, along with mesic and frigid temperature regimes. But soil moisture regimes often border on ustic in the southeastern portion of its range.

Figure 2-8—The Utah juniper southern boundary occurs in the high mountains of the Mojave and Sonoran deserts in southern California and Arizona, where it is associated with blackbrush. Southwest corner of Utah. (Photo by Rick Miller, Oregon State University.)

Figure 2-9—The northern range of Utah juniper occurs in Wyoming crossing into the very southern portion of Montana in the Pryor Mountains. Wind River Canyon of central Wyoming. (Photo by Rick Miller, Oregon State University.)

Utah juniper is a small monoecious (sometimes dioecious) tree 10 to 20 feet tall (Cronquist et al. 1972) but it can exceed heights of 40 feet. It often has one to three trunks or multiple main upright branches nearly the same size as the trunk. The scale-like leaves are 0.08–0.12 inches (2-3 mm) long with serrated margins (Willson et al. 2008) and are mostly opposite in twos or (rarely) in threes. Resin glands on the leaf scales are deeply imbedded in the mesophyll and often difficult to see (fig. 2-10). Unlike western juniper, they do not exude resin. Female cones are usually blueish-brown or reddish-brown beneath the glaucous, contain one to two seeds, and are 0.31–0.35 inches in diameter, with extremes 0.24–0.47 inches (8–9 mm, extremes 6–12 mm) in diameter (fig. 2-11).

Figure 2-10—Young female cones developing in the leaf axials of the leaf scales in Utah juniper. Note the lack of resin glands occurring on the leaf scale surface, which occur in western juniper. (Photo by Rick Miller, Oregon State University.)

Figure 2-11—Usually blueish-brown and reddish-brown beneath the glaucous, Utah juniper cones contain one to two seeds and take two growing seasons to produce mature fruit. (Photo by Rick Miller, Oregon State University.)

Western Juniper (Juniperus occidentalis Hook.*)*

Western juniper grows north of singleleaf pinyon and Utah juniper woodlands in central and eastern Oregon, southwestern Idaho, northern and northeastern California, northwestern Nevada, and north into Washington (fig. 2-1; tables 2-1, 2-2). It occupies elevations between 600 and 6,000 feet (Gedney et al. 1999) and (uncommonly) above 7,000 feet (Miller et al. 2005). It grows on a wide variety of soils and parent materials derived from aeolian, sedimentary, and igneous sources (Driscoll 1964; Miller et al. 2005). Soil textures range from coarse, sandy to heavy clays and soil moisture regimes of xeric and xeric-aridic. Most western juniper are found on frigid soil temperature regimes or intergrades between mesic and frigid and rarely on cryic soils. The highest densities of western juniper are found on moderately deep Mollisol soils, of which the majority are young trees (less than 150 years). On shallow to moderately deep soils, it is commonly associated with Wyoming and mountain big sagebrush. When growing on shallow to very shallow soils (underlain by bedrock or claypans including Camborthids, Duragids, and Haplargids), western juniper forms open low-density canopies associated with low sagebrush.

Western juniper is a submonecious tree typically 12 to 35 feet tall, though reaching heights exceeding 60 feet (Adams 2014; Cronquist et al. 1972; Miller et al. 2005). Leaf scales are usually opposite, or in whorls of three, with a serrated leaf margin. Leaves contain conspicuous resin glands, exuding resin that forms a white crust on the leaf scales—a useful characteristic for separating western from Utah juniper (fig. 2-12). In northwestern Nevada and northeastern California, it is common to find western and Utah juniper hybrids, with a single tree having both well-developed exuding and inconspicuous nonexuding resin glands (Terry et al. 2000; Vasek 1966). Male cones are 0.1–0.2 by 0.08–0.12 inches (3–5 by 2–3 mm) in size and form on the ends of the short branchlets. Female cones are approximately 0.28–0.35 inches (7–9 mm) bluish-black at maturity, covered with a resinous pulp, and contain one to two (sometimes three) seeds.

Figure 2-12—Western juniper male cones just prior to pollination in the early spring. Leaf scales are usually opposite or in whorls of three and contain obvious ruptured resin glands on the back of the leaf scales, which are visible but usually not ruptured on Sierra juniper, and not visible on Utah juniper. (Photo by Rick Miller, Oregon State University.)

Sierra juniper, *Juniperus occidentalis* Hook. var. *australis* Vasek, once grouped as a variety of western juniper, has been identified as a separate species, *J. grandis* (Adams 2014). A form of western juniper has also been recently identified as *J. occidentalis* forma *corbetti*, located just east of Bend, Oregon, exhibiting a growth form of a compact shrub (Adams 2014).

Rocky Mountain Juniper (Juniperus scopulorum Sargent, Gard. & Forest*)*

Rocky Mountain juniper has the widest distribution among both pinyon and juniper species in the West (fig. 2-2). It is found at sea level (San Juan Islands) but more commonly between 4,000–9,000 feet in the southern part of its range and 2,000–7,500 feet in the northern portion of its range. Its distribution extends from southcentral New Mexico north into Canada (fig. 2-13; Adams 2014). Most commonly it occurs throughout the Rocky Mountains in both the United States and Canada and along the Mogollon Rim in Arizona. It grows in clay, rocky, and sandy textured soils derived from limestone, basalt, and sandstone—and in typically cooler environments than Utah juniper or western juniper (fig. 2-4a,b). Along its eastern boundary, it hybridizes with eastern red cedar, forming the subspecies *Juniperus virginiana* var. *scopulorum*. It also hybridizes with creeping juniper.

Rocky Mountain juniper is a dioecious, typically single-stemmed tree up to 60 feet tall with a pyramidal to occasionally round top (Adams 2014; Cronquist et al. 1972). Leaf scales are usually opposite, but sometimes in whorls of three, and usually not overlapping or less than 1/5 of the length, and with inconspicuous resin glands. Leaf margins are entire, unlike the serrated leaf scales in Utah and western junipers (Willson et al. 2008). Leaf branches are also considerably more slender than Utah or western junipers. Male cones form on the branch tips and are very small, 0.08–0.12 inches (2–3 mm). Seed cones are 0.24–0.35 inches (6–9 mm) in diameter, light blue with heavy glaucous, but dark blue beneath. There are usually one to three seeds per cone.

Figure 2-13—Rocky Mountain juniper has the most extensive range of junipers that occur in the West, extending north into Canada and south along the Mexico border. Garden of the Gods, east slope of the Rocky Mountains. (Photo by Rick Miller, Oregon State University.)

Sierra Juniper (Juniperus grandis R.P. Adams*)*

Also known as grand juniper and big western juniper, Sierra juniper grows from Lassen County in northeastern California, south along the east slopes of the Sierra Nevada Mountains, to the San Bernardino Mountains (Vasek 1966), typically between 3,300–10,000 feet (fig. 2-14; Adams 2014). It also extends east into the central and northern Nevada mountain ranges where it grows at moderately high elevations well above Utah juniper (Charlet 1996). It occupies cooler sites than western or Utah junipers (fig. 2-4a). In the Sierra Nevada Mountains, it is often associated with subalpine forests and in central Nevada with high sagebrush or mountain brush communities.

Once considered a subspecies of western juniper (*J. occidentalis* subsp. *australis*), Sierra juniper is mostly dioecious and can attain a larger size (up to 100 feet) than western juniper (Vasek 1966). Leaf scales are mostly in threes with visible glands that often do not exude resin (Adams 2014). Development of both male and female cones is similar to western juniper, with one to two and sometimes three seeds per cone.

Singleleaf Pinyon (Pinus monophylla var*. monophylla* Torr. & Frém.*)*

First described by John C. Fremont in 1944, singleleaf pinyon is also known as singleneedle pine, nut pine, one-leaf pine, *piñon*, or pinyon. It grows throughout much of the Great Basin in Nevada, throughout western Utah, and along the east slopes of the Sierras south to southern California and north to southern Idaho (fig. 2-2; tables 2-1, 2-2). Annual precipitation most commonly ranges between 10 and 16 inches, with extremes as low as 8 or as high as 18 inches, of which the majority occurs during the winter and spring and less than 25 percent occurring during the summer months (fig. 2-2). Singleleaf pinyon typically grows between 3,300–9,000 feet in elevation (as high as 9,700 feet in the White Mountains of California) on coarse-textured soils derived from a wide variety of parent materials with surface pH commonly between 6.0–8.0 (Meeuwig et al. 1990). Soil moisture and temperature regimes are most commonly frigid or mesic bordering on

Figure 2-14—Sierra juniper rooted in the granitic walls of the High Sierras in Yosemite National Park at 8,500 ft. In the Sierras this species often grows at timberline. (Photo by Rick Miller, Oregon State University.)

frigid. It is most commonly associated with Utah juniper, but at higher elevations it mixes with the lower boundaries of ponderosa, limber, and bristlecone pines and Douglas-fir.

Trees are typically 15 to 50 feet tall often with one to three main stems. Leaves are 1.2–2 inches (30–50 mm) long and mostly one needle, but a small percentage supporting two needles per fascicle are commonly found in the southeastern portion of its range (Cronquist et al. 1972). See below for pinyon varieties. Male cones are 0.24 inches (6 mm) long. Female cones are broadly ovoid 1.4–2 inches (35–55 mm) but occasionally up to 3.1 inches (80 mm) long and occurring subterminal or lateral on the branchlets (fig. 2-15). Seeds are 0.51–0.67 inches (13–17 mm) long.

Twoneedle Pinyon (Pinus edulis Engelm.*)*

Twoneedle pinyon, also known as Colorado pinyon, nut pine, twoneedle pinyon, and two-leaf pinyon, occurs along the Wasatch Mountains, the boundary between the Great Basin and where it can mix with singleleaf pinyon and the Colorado Plateau. It extends east and south from the Wasatch and Colorado Plateau well into New Mexico, southern Colorado, and the extreme western edge of Oklahoma and west Texas (fig. 2-2). Its southern-most boundary is southern New Mexico and extends north near the Wyoming, Colorado, and Utah border. The range of twoneedle pinyon generally has milder winter temperatures and greater proportions of summer annual precipitation than the range of singleleaf pinyon. Twoneedle pinyon primarily occupies the rocky plateaus, mesas, foothill terraces, and lower mountain slopes between 4,500– 7,500, up to 8,500 feet, in the Colorado Plateau (Cronquist et al. 1972; Ronco 1990). Total annual precipitation is widely variable, ranging between 10–22 inches with summer precipitation exceeding 3 inches (West et al. 1978a). This species grows in a wide variety of soil depths and textures ranging from very coarse to fine compacted clays (Ronco 1990). Just over 50 percent of this species grows on mesic-aridic/ustic moisture regime. It is frequently associated with Utah juniper, alligator juniper, oneseed juniper, and Rocky Mountain juniper.

Figure 2-15—In pinyon pines, portions of three growing seasons are required to produce mature seeds. The exact timing of the developmental events varies among pinyon species and with the elevation or latitude of the pine stand. Great Basin National Park. (Photo by Rick Miller, Oregon State University.)

Trees can grow up to 50 feet but are usually smaller (Cronquist et al. 1972). Needles are 0.8–1.6 inches (20–40 mm) long and mostly two per fascicle, but occasionally 1 or 3 (see pinyon varieties below). Male cones are 0.24 inches (6 mm) long. Female cones ovoid 0.8–2 inches (20–50 mm) long with seeds 0.39–0.63 inches (10–16 mm) long occurring subterminal or lateral on the branchlets.

Pinyon Varieties

Pinus monophylla var. *monophylla* is the predominant pinyon found throughout the Great Basin. However, two other subspecies are recognized by some taxonomists, which occupy different environments (Bailey 1987; Cole et al. 2008a; Eckenwalder 2009; Little 1968). Variety *Pinus monophylla* var. *californiarum* (Bailey 1987) like var. *monophylla*, grows in areas with wet winters and dry summers, but with warm rather than cold winters. It primarily grows in southern California south into Baja. Both Bailey (1987) and Cole et al. (2008a) suggest *Pinus monophylla* var. *californiarum* should be a separate species, *Pinus californiarum.* Variety *fallax*, is believed to be genetically closer to twoneedle pinyon and is considered a variety of this species by some taxonomists (Cole et al. 2008a; Little 1968). It grows just south of the Mogollon Rim in Arizona in areas with wetter summers than the other singleleaf pinyon varieties, but like var. *californiarum*, warm winters. Variety *fallax* usually grows south and at lower elevations than twoneedle pinyon and in areas with more extreme May and June droughts similar to californiarum, which is associated with stronger winter precipitation (Cole et al. 2008a).

Morphology

Foliage

Juniper leaves are reduced small scales that form an oblique triangle. The edges are serrated in all of the western species with the exception of Rocky Mountain juniper, which are smooth, similar to eastern redcedar (Willson et al. 2008). Leaf margins in adult foliage are slightly recurved, creating a slight cupping, which seals one leaf margin against the other—forming a chain-like cylinder of scales against the stem (figs. 2-10, 2-12; Miller and Shultz 1987). The leaf surface facing toward the stem (adaxial) is not exposed to sunlight or air movement, which significantly reduces potential transpiration. The epidermis is heavily cuticularized, to the extent the cell lamina are nearly obliterated. In western juniper, the majority of stomates are distributed on the protected adaxial surface (fig. 2-16a). On the surface facing away from the stem, stomates are restricted to the base of the leaf that is entirely covered by the adjacent subtending scale leaf (fig. 2-16b).

Leaf morphology of western juniper (and most likely other junipers in the West) allows for increased drought avoidance through low surface-to-volume ratios, thick cuticle layers, and protected stomates. Mean maximum leaf conductance (transpiration passing through the leaf surface to the atmosphere) per unit of leaf area is less in western juniper than values reported for other conifer species (Miller and Shultz 1987). Juniper leaf scales develop slowly and can remain functional on the tree for 6 or more years (Peek et al. 2006; Reich et al. 1992) leading to nearly constant leaf area displayed throughout the year (Grier et al. 1992; Hicks and Dugas 1998; Miller et al. 1992). Juniper foliage has a high cost of development and low assimilation rates (Reich et al. 1992), typical of the foliage of plants adapted to dry, nutrient-poor environments (Reich et al. 1992). In juvenile foliage, the triangular leaf scales in juniper do not compress against the adjacent leaf scale but spread from the stem (fig. 2-17). This growth form is found on very young trees and sometimes at the base of adult trees after top removal. The juvenile foliage allows for increased sunlight and absorption of CO_2 resulting in higher photosynthesis rates compared to adult foliage but has poorer stomatal control resulting in lower water use efficiency than adult foliage (Miller et al. 1992).

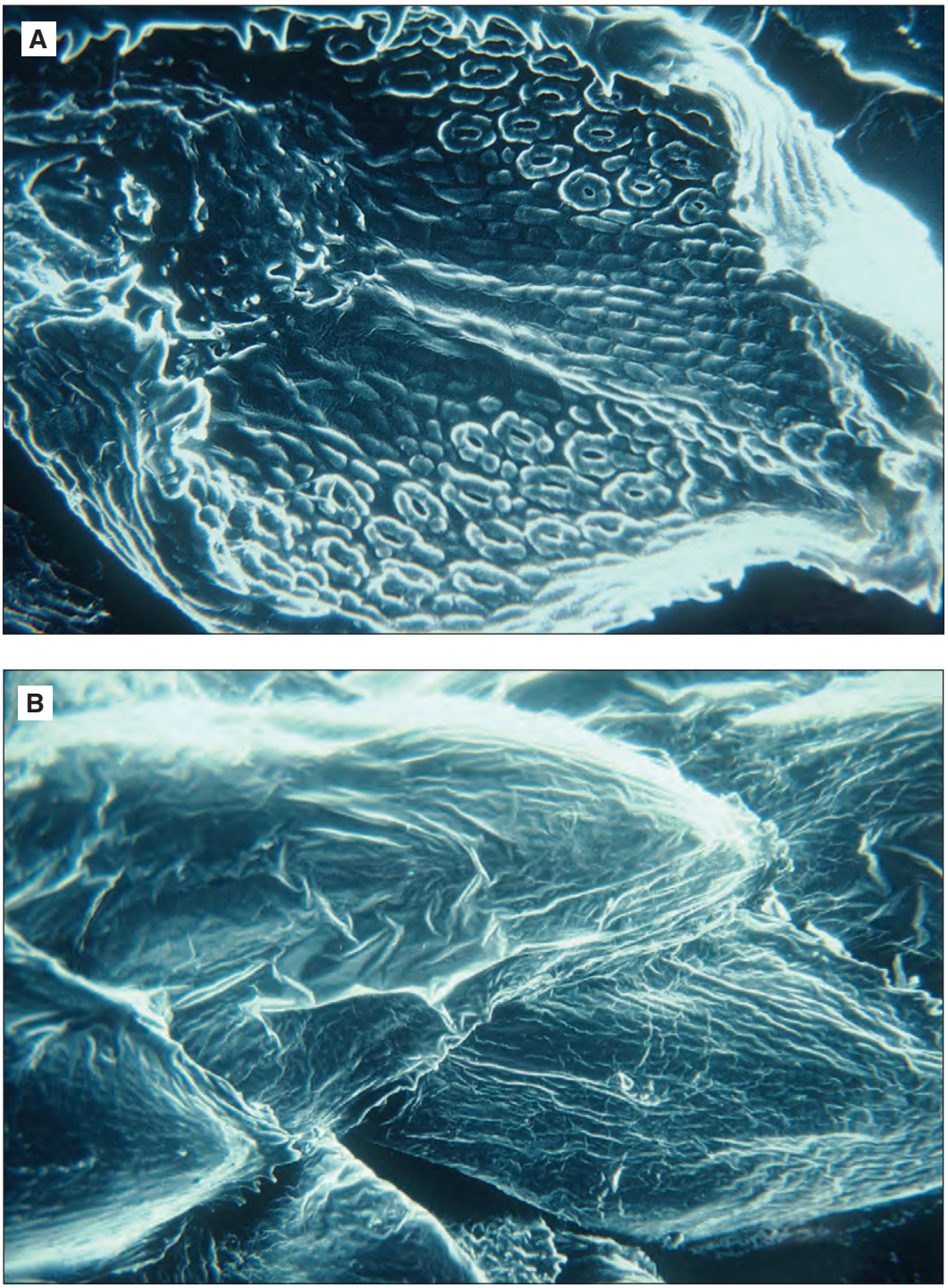

Figure 2-16—(A) The leaf surface of western juniper that faces the stem (adaxial), where the majority of stomates are located, is not exposed to sunlight or air movement—which significantly reduces potential transpiration and increases photosynthetic efficiency per units of water used. (B) On the exposed leaf scales of western juniper facing away from the stem, stomates are restricted to the base of the leaf scale, which are entirely covered by adjacent subtending scale leaf. The epidermis on the outer leaf scale is heavily cuticularized, which further reduces water loss in hot, dry environments. (Photo from Miller and Schultz 1987.)

Figure 2-17—In juvenile juniper foliage, the triangular leaf scales do not compress against the adjacent leaf scale but spread from the stem. The juvenile foliage on juniper allows for increased sunlight and absorption of CO_2 resulting in higher photosynthesis rates compared to adult foliage but has poorer stomatal control resulting in lower water use efficiency than adult foliage. (Photo by Rick Miller, Oregon State University.)

Pinyon pine needles have thick waxy cuticles with the stomates set within small depressions increasing the boundary layer protecting them from arid environments. Singleleaf pinyon needles contain 2–7 resin ducts and 17–30 stomatal lines (Cole et al. 2008a). Twoneedle pinyon needles contain 2–3 resin ducts and 8–15 stomatal lines. The resin ducts are important defense mechanisms against insects and other animals in creating a distasteful substance and disrupting digestion. Singleleaf pinyon needles can stay functional for 8–12 years (Tausch and West 1987).

Roots

Work on juniper and pinyon roots is very limited and is based on a low number of tree excavations, especially for mature trees. Root depth, lateral spread, and shoot-to-root ratio within each species likely vary with substrate, depth to restrictive layer, fracturing of the restrictive layer, and moisture availability. Mature pinyon pine, western juniper, and likely Utah juniper have extensive lateral roots that typically extend one to three times the height of the tree, have a fine root mat directly beneath the tree canopy, and lack or have just a stunted tap root (fig. 2-18; Everett 1984; Russell and Honkala 1990; Rick Miller, Professor Emeritus, Range Ecology, Oregon State University, Corvallis, Oregon, personal observation, 1985. Juniper and pinyon roots are capable of penetrating depths of more than 20 feet, especially in substrates that are fractured, allowing both water and roots to attain considerable depths (fig. 2-19; Cannon 1960; Foxx and Tierney 1987; Rick Miller, personal observation). However, taproots are important for tree seedlings. Taproot growth in twoneedle pinyon is rapid, averaging 7–11 inches in the first year (Harrington 1987). In western juniper, root development is primarily a taproot during the first 10 years of growth (Kramer 1990).

Figure 2-18—Mature pinyon pine, western juniper, and Utah juniper (see fig. 2-5) have extensive lateral roots that typically extend one to three times the height of the tree. They have a fine root mat directly beneath the tree canopy and no—or just a stunted—tap root. Southcentral Utah. (Photo by Rick Miller, Oregon State University.)

Figure 2-19—Juniper and pinyon roots are capable of penetrating depths more than 20 feet, especially in substrates that are fractured, allowing both water and roots to attain considerable depths. Singleleaf pinyon. Southcentral Utah. (Photo by Rick Miller, Oregon State University.)

As trees mature, taproot development declines and often dies when juvenile foliage is replaced by adult foliage (Young et al. 1984). After 10 years, lateral root development increases accounting for 65 percent of the root biomass in trees 30–35 years old (Kramer 1990). Trees less than 0.25 inches and 0.25–0.6 inches in basal diameter had lateral roots extending 90–100 inches and 120–225 inches, respectively (Miller et al. 1990). Seasonal growth and mortality of roots are related to soil moisture and temperature. Fine root growth in Utah juniper followed a seasonal progression from the surface toward the lower soil depths as the growing season progressed. (Peek et al. 2006). As temperatures increased, root loss increased in the upper soil layers. The average life span of shallow and deep fine roots was 5–15 months, respectively.

Seed and Seedling Ecology

The production of pinyon and juniper seeds and their subsequent fates determine the ability of the different species to maintain existing populations and expand into new areas. In this section, we summarize and update earlier publications on the seed and seedling ecology of pinyon and juniper species (Chambers et al. 1999a,b). We begin by reviewing factors that influence seed production, and then discuss the potential pathways and fates of seeds from seed or fruit development to seedling establishment. The seed fates of pinyon and juniper species differ and are illustrated in seed and seedling fate diagrams for pinyon (fig. 2-20) and junipers (fig. 2-21; Chambers et al. 1999a).

Seed Production

In pinyon pines, portions of three growing seasons are required to produce mature seeds (fig. 2-20). The exact timing of the various developmental events varies among pinyon species and with the elevation or latitude of the pine stand. Like all pines, pinyons are monoecious and both male and female cones occur on the same plant (Mirov 1967; Vidakovic 1991). Male and female cones (strobili) of twoneedle pinyon form between August and October and develop the following spring (Jeffers 1994; Little 1938, 1941). Pollination is usually complete by the end of June, but seeds do not mature until September of the following year. Cone production can occur on trees 3–4 feet tall and 10–20 years old, but the largest crops are produced on mature trees, which are usually greater than 20–30 years old (Jeffers 1994).

Many of the seeds produced are unfilled or are eaten by insects before they mature. In twoneedle pinyon, nearly half of the seeds in mature cones are empty (Ligon 1978; Vander Wall and Balda 1977). In singleleaf pinyon in the Pine Nut Range of western Nevada, 18 percent and 21 percent of the seeds were empty during two successive years (Stephen Vander Wall, Professor, Department of Biology, University Nevada, Reno, unpublished data). A variety of insect species feed on the developing cones and seeds of pinyon pines. The two most important types are *Conophthorus* and *Dioryctria* (Christensen and Whitham 1991, 1993; Keen 1958). *Conophthorus* species are cone beetles whose larvae eat through the cone scales and seeds, causing second-year cones to die. In some years, beetle larvae can destroy up to 90 percent of the cone crop (Keen 1958). The larvae of *Dioryctria albovitella*, juvenile moths known as "pine coneworms," attack terminal shoots and developing cones, reducing cone production, viable seed production, and seed mass (Christensen and Whitham 1991, 1993; Mueller et al. 2005b). Twoneedle pinyon trees susceptible to moth attack had 93–95 percent lower cone production—and surviving cones produced 31-37 percent fewer viable seeds—resulting in a 96–97 percent reduction in whole tree viable seed production (Mueller et al. 2005b). Because seed germination is positively associated with seed size, seedling biomass, and seedling height, trees suffering chronic herbivory likely produce lower quality offspring (Mueller et al. 2005b).

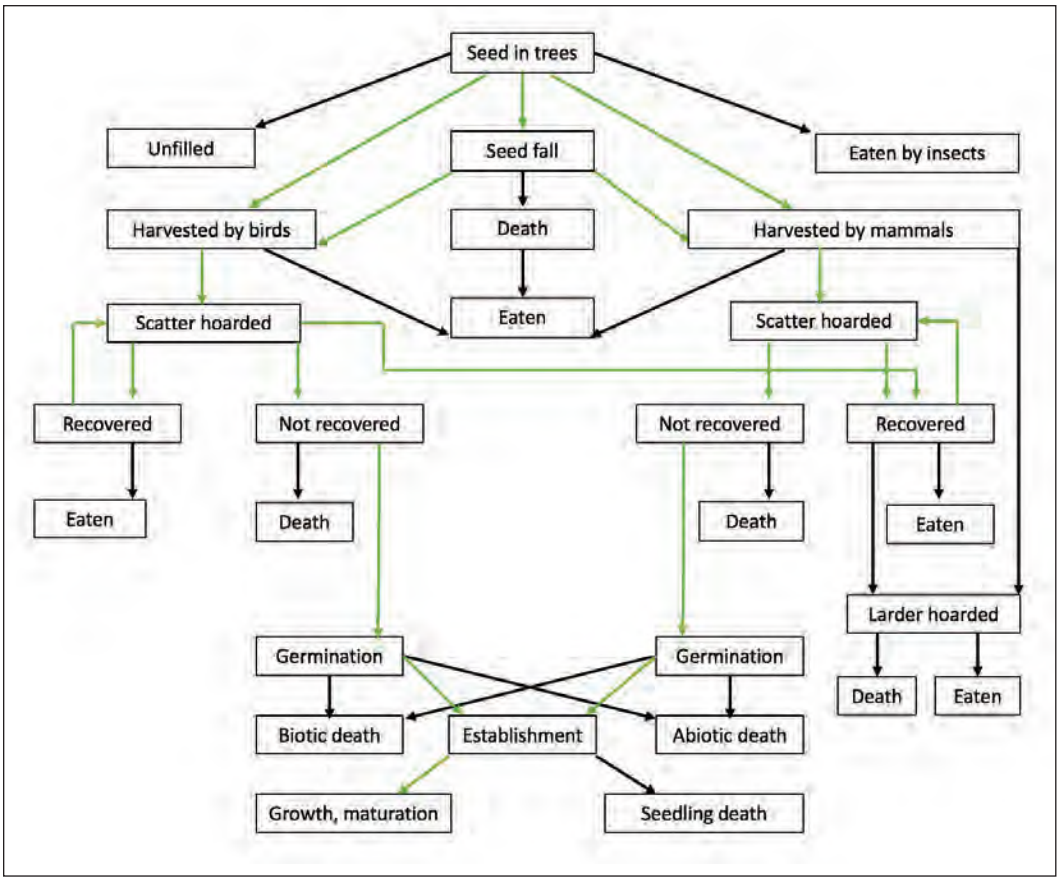

Figure 2-20—Seed fate diagram for pinyon pines from Chambers et al. 1999. Slightly more than 2 years are required to produce mature "seeds in the trees." Many seeds are unfilled because of environmental and developmental constraints. Others are eaten by insects or animals before they fully develop. Seeds that do mature are harvested or eaten by a variety of animals, some of which act as seed predators and others as seed dispersers. Birds (corvids such as jays and nutcrackers) and rodents (chipmunks, mice, and kangaroo rats) harvest and disperse pinyon seeds. Although birds eat some seeds, they scatter-hoard many others in shallow caches in the soil. A portion of cached seeds are recovered and eaten at a later date or recovered and moved to new locations to avoid predation by competitors. Cached seeds not recovered by birds or rodents either die of abiotic or biotic causes or survive to germinate. A portion of rodent harvested seed may end up in large underground larders, where they likely are consumed or die due to unsuitable germination and establishment conditions. Regardless of the disperser, if the seed ends up in a microhabitat suitable for germination and growth, seedling establishment can occur. Seedlings are then susceptible to rodent predation, insects, or pathogens. Seed dispersed to a microhabitat unsuitable for growth and survival will die.

Jeffers (1994) reported mean filled seeds per cone in twoneedle pinyon as 10–20 seeds, while other reports range from about four in twoneedle pinyon (Ligon 1978; Vander Wall and Balda 1977) to about 16 in singleleaf pinyon after accounting for the various forms of predispersal seed losses (Vander Wall 1997). During a year of heavy seed production, large trees can produce more than 1,000 cones, although the average tree produces less. A typical mean seed crop during a year of heavy cone production ranges from 2,000–8,000 filled seeds per tree, but values for individual trees vary tremendously. Seed production in a stand of singleleaf pinyon in the Pine Nut Range of western Nevada was 1,873 filled seeds per tree in a year of moderate cone production and 5,936 filled seeds per tree in a year of relatively heavy cone production (Vander Wall 1997).

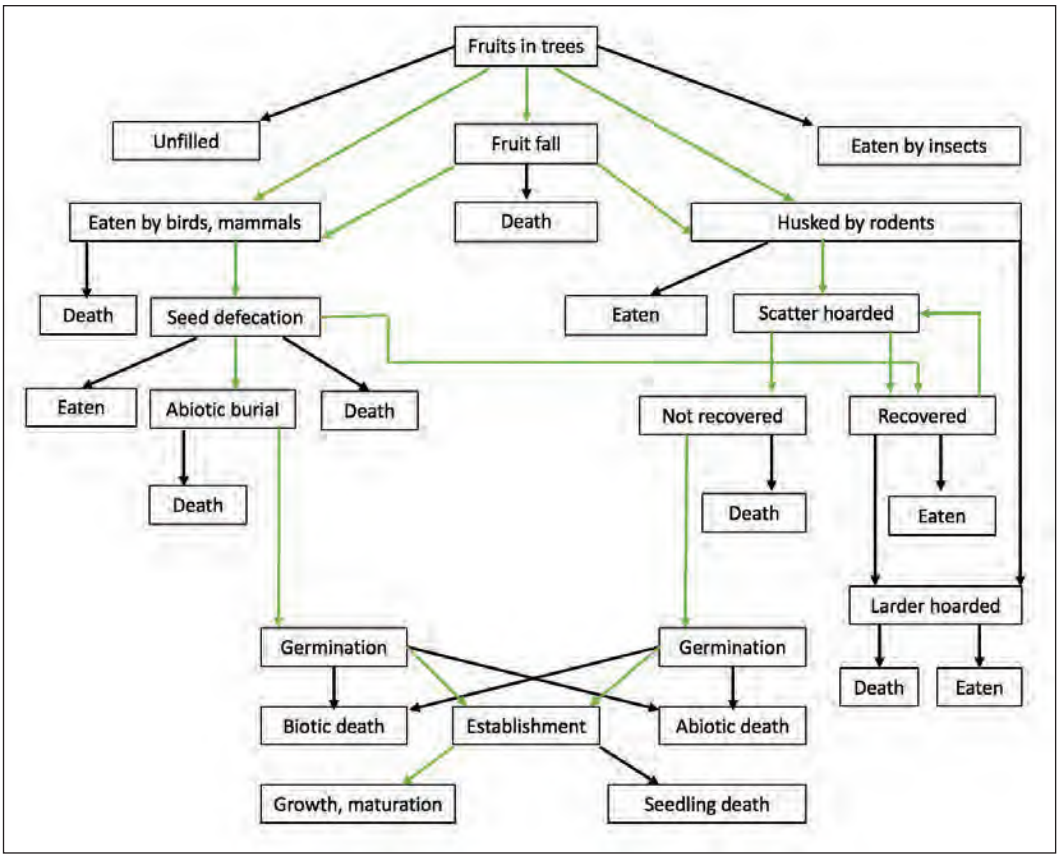

Figure 2-21—Seed fate diagram for juniper from Chambers et al. 1999. In juniper species, seed maturation takes two growing seasons. Many of the seeds produced are unfilled due to environmental and developmental constraints. Others are eaten by insects or destroyed by animals. Seeds that do develop and mature are harvested or eaten by a variety of animals, some that act as seed predators and others that serve as seed dispersers. Juniper seeds are adapted for dispersal by frugivorous birds and mammals that either eat the seeds while they are on the trees or after they fall to the ground. If the fruits are ingested by frugivorous mammals, the pericarps are digested by the animals and seeds defecated onto the ground.

Depending on species of juniper and animal disperser, some seeds are killed. Many survive ingestion only to be eaten later by other animals or die of abiotic or biotic causes. Surviving seeds may remain on the soil surface or be buried abiotically where additional mortality or germination may occur. Seeds can also be scatter-hoarding by rodents such as chipmunks, mice, and kangaroo rats. Many cached seeds are later recovered and eaten, but others are probably recached. Some cached seeds are not recovered by rodents and die of abiotic or biotic causes, while others survive to germinate. Some seeds may be placed in large underground larders, where the majority are either eaten by the rodents or die because of unsuitable conditions for germination and establishment. Regardless of the disperser, if the seed has been dispersed to a microhabitat with environmental conditions suitable for germination and growth, seedling establishment can occur. However, seedlings may still be susceptible to rodent predation, insects, or pathogens. If the seed has been dispersed to a microhabitat unsuitable for growth and survival, mortality by biotic or abiotic causes is inevitable.

Climate warming and associated droughts have the potential to cause significant declines in pinyon cone production. In twoneedle pinyon, seed cone production declined by 40 percent from the 1974 decade (1969–1978) to the 2008 decade (2003–2012) in revisited stands throughout New Mexico and northwestern Oklahoma (Redmond et al. 2013). Seed cone production was negatively correlated with late summer temperatures at the time of cone initiation. Further, declines in seed cone production were greatest among populations that experienced the greatest relative increases in growing season temperatures, which were

the populations located at the cooler, upper elevations. Drought predisposes twoneedle pinyon to bark beetles, which feed on the phloem of the trees (Gaylord et al. 2013). However, less is known about effects on insects that attack cones and seeds.

In Utah juniper and western juniper, it takes two growing seasons following pollination to produce mature "fruits in the trees" (figs. 2-10, 2-11, 2-21; Adams 1993; Fechner 1976). Most juniper species (table 2-2), including oneseed juniper, are dioecious with male and female cones produced on separate trees (Adams et al. 2014; Johnsen 1962). However, western juniper and California juniper may be either dioecious or monoecious, and Utah juniper is generally monoecious (Adams 1993; Johnsen and Alexander 1974; Tueller and Clark 1975). Reproductive phenology varies with species and climate, but in most junipers, male cones mature in late summer to fall and release pollen in spring as female cones are emerging (Fechner 1976; Tueller and Clark 1975; Eugene Schupp, Professor, Wildland Resources/Ecology Center, Utah State University, Logan, Utah, unpublished data). A delay of several months to a year or more between pollination and fertilization is typical with maturation occurring a year or more later.

Some species produce only a single (sometimes two) seed per cone (e.g., Utah juniper and oneseed juniper), others produce one to three seeds per cone (western juniper), while still others mature four to five or more seeds per cone (e.g., alligator juniper, also known as checkerbark juniper) (Adams 1993; Dimitri et al. 2018). Ripe fruits can remain on the tree for 2 or even 3 years in some species. Although seed bearing begins at 10–20 years of age (Johnsen and Alexander 1974), significant fruit production starts at 50–70 years and continues for centuries (Eddleman 1984; Miller and Rose 1995; Noble 1990; Tueller and Clark 1975). As with pinyon pine, there is extensive loss of potential seed production between pollination and seed maturation with many fruits failing to fill or being eaten by insects or other predators (fig. 2-21). Junipers ripen many fruits with fully developed seed coats—but without an embryo or endosperm (Adams et al. 2014; Fuentes and Schupp 1998; Johnsen and Alexander 1974; Noble 1990). The proportion of unfilled seeds is highly variable, both among and within species and over time.

In 1993 in Tintic Valley, western Utah, seed fill of Utah juniper varied from 0 to 17.3 percent among individuals with a mean of 5.6 percent filled (Fuentes and Schupp 1998). In the same year, Utah juniper had less than 1 percent of its seeds filled at U.S. Army Dugway Proving Grounds about 50 km (31 miles) away. Three years later it produced roughly 33 percent filled seeds (Fuentes and Schupp 1998; Eugene Schupp, professor Utah State University, unpublished data). Similarly, in 2010, seed fill in Utah juniper ranged from 0 percent for Big Cottonwood Canyon, Utah, to 79 percent for Sedona, Arizona (Adams et al. 2014). In 2011, the same Big Cottonwood Canyon population had 0.4 percent filled seeds, while the Sedona, Arizona, population had dropped to 7.2 percent. The causes of unfilled seeds are poorly understood in juniper, but it is thought that the proportion of filled seeds varies with the age, structure, density, and community composition of a stand, in addition to physiography and weather during pollination and/or seed development (Noble 1990).

Seed production can be significantly impacted by invertebrate and vertebrate predation on developing seeds. Caterpillars of the moths *Periploca atrata* feed on juniper seeds, consuming the entire embryo and endosperm (Furniss and Carolin 1977; Keen 1958; Powell 1963), and the cecidomyiid midge *Walshomyia juniperina* (fig. 2-22a,b) eats the fruit of Utah and western junipers (Furniss and Carolin 1977). The juniper-berry mites *Trisetacus quadrisetus* and *Eriophyes ramosus* have been known to destroy the entire fruit crop of some trees (Furniss and Carolin 1977; Morgan and Hedlin 1960). Fernandes and Whitham (1989) found that the larvae of an unidentified beetle (*Anobiidae*) infested oneseed juniper near Sedona, Arizona, and that insect attack increased the likelihood of fruit abscission.

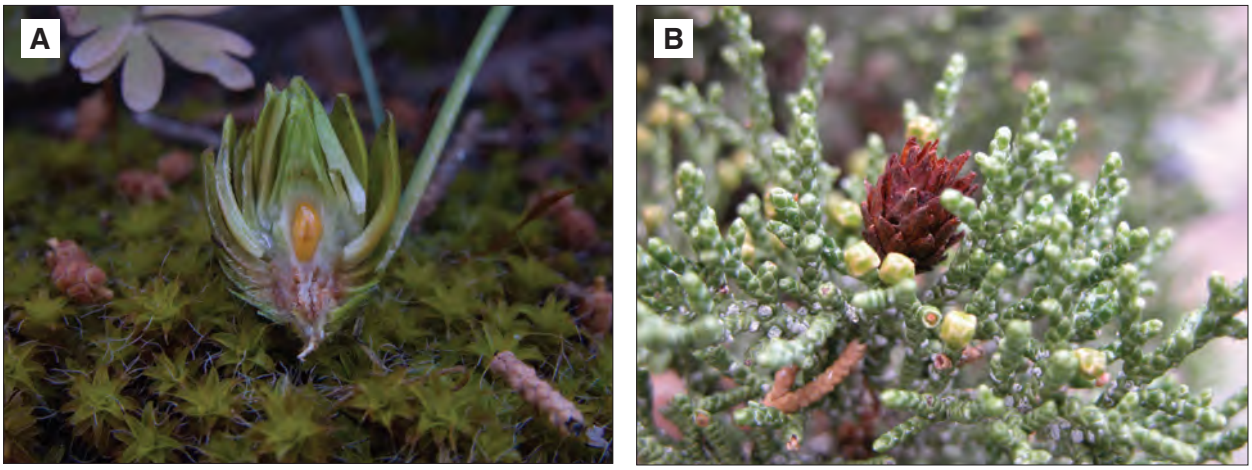

Figure 2-22—Artichoke-like gall (a and b) located on the brachlet of junipers (frequently misidentified as a reproductive structure) is formed by the midge larvae *Walshomyia juniperina.* (Photo by Rick Miller, Oregon State University.)

In an early study of western juniper, the chalcidoid wasp *Eurytoma juniperina* destroyed about 25 percent of the seed crop near Hilt, California, in 1913 (Keen 1958). More recently, a study at two sites in northeast California had over 30 different species of arthropods (insects and arachnids) associated with the fruits or seeds of western juniper (Dimitri et al. 2014, 2017; Tonkel et al. 2014). These included frugivorous and granivorous species (cone- and seed-feeders, respectively), predators of other insects, parasitoids (insects that develop from eggs laid inside other insects, ultimately killing their host), hyperparasitoids (parasitoids of other parasitoids), and inquilines (species that harmlessly cohabitate with other species). The seed-destroying arthropods collected included species of several insect orders, such as beetles, moths, wasps, and flies, as well as a family of mites. Seed damage by all arthropod taxa varied both spatially and temporally, and masting (cone producing) events overwhelmed the responses of seed predators (Dimitri et al. 2017). This research shows that junipers harbor a diverse and complex community of arthropods in their berries, some of which can drastically reduce a tree's seed-yield within a given year.

Seed Dispersal Processes

To understand plant dispersal processes, information on both the types and behaviors of the seed dispersers and the effectiveness of dispersal for plant establishment is necessary. Disperser effectiveness has been defined as "the contribution a disperser makes to the future reproduction of a plant" population (Schupp 1993; Schupp et al. 2010). Effectiveness has a quantitative component (the number of seeds dispersed) and a qualitative component (the likelihood that a dispersed seed will survive to produce a new plant in the population). Here, we examine the available information on both the types and behaviors of the animals that disperse pinyon and juniper, and the effectiveness of those dispersers.

Seed dispersal of pinyon pines by birds has been relatively well studied. Several species of corvids—jays and nutcrackers (for common and scientific animal names see Appendix A)—that store seeds in shallow caches in the soil disperse pinyon pine seeds (Vander Wall 1990; Vander Wall and Balda 1981). Pinyon pine cones and seeds are well adapted for dispersal by birds. The seeds are large and nutritious (Botkin and Shires 1948). The dry mass of the edible portion of twoneedle pinyon seeds weighs 125–225 mg and that of singleleaf pinyon seeds weigh 200–300 mg. Twoneedle pinyon seeds are very high in fats (63 percent), whereas singleleaf pinyons have less fat (26 percent) but are rich in carbohydrates with 60 percent (Botkin and Shires 1948, values adjusted to

dry weight). The cones are weakly constructed so that the seeds can be easily extracted by corvids with long pointed beaks, such as Clark's nutcracker and pinyon jays (Vander Wall and Balda 1981). Seeds are enclosed in deep pockets and held by thin flanges so that they do not fall readily from the cones (fig. 2-15). Seeds of twoneedle pinyon and singleleaf pinyon have thin coats, and even small birds such as mountain chickadees and red-breasted nuthatches are able to open the seeds. Unlike many conifers, cones are primarily pointed to the side and upward, which not only retards seed loss, but increases the visibility and availability of the seeds to avian dispersers.

Birds typically disperse seeds from several feet to 3.1 miles (Vander Wall and Balda 1981). Differences in dispersal distances exist among different bird species with the more solitary scrub jays seldom dispersing seeds more than 0.62 miles, the gregarious pinyon jays carrying seeds slightly farther, and Clark's nutcrackers carrying seeds as far as 13.7 miles (Vander Wall and Balda 1981). While jays typically place one seed in each cache site, nutcrackers cache from 1–10 seeds with a mean of about 4 seeds per cache. While many of the cached seeds are recovered and eaten by the birds, others are not recovered and thus have the potential to germinate and produce seedlings. Although not well documented, some of the recovered seeds are probably re-cached in new locations to avoid predation by competitors in what has been termed "shell games" in animals (e.g., Vander Wall 1995; Vander Wall and Joyner 1998). These re-cached seeds may be recovered once again and then either eaten or moved to yet another location. The total number of seeds cached can be phenomenal. In a good seed crop year, individual Clark's nutcrackers scatter-hoard (creating multiple caches) between 22,000 to 33,000 twoneedle pinyon seeds (Vander Wall and Balda 1977) or 17,900 singleleaf pinyon seeds (Vander Wall 1988). Ligon (1978) estimated that a flock of 250 pinyon jays could cache about 4.5 million pinyon seeds over 5 months.

Seed caching by corvids has important consequences for the fate of a pinyon pine seed. It can be quantitatively effective for pinyon pine as large numbers of seeds are cached and—especially in large seed crop years—many are left unrecovered to germinate and possibly establish. Bird dispersal can also be qualitatively effective because pinyons almost always require burial for establishment, and birds bury the seeds 0.8–1.6 inches (20–40 mm) in the soil (Stephen Vander Wall, Professor, Department of Biology, University of Nevada, Reno, personal observation, 1985). However, pinyon often have a nurse plant and shading requirement and birds tend to place most seeds in interspace environments, not in more favorable microhabitats under trees or shrubs (Stephen Vander Wall, personal observation).

Pinyon pine seeds are also cached by rodents. Rodents prefer pinyon over other native seeds, such as desert peach, antelope bitterbrush, and Utah juniper (Vander Wall et al. 2019). Unlike corvids, most rodents forage for seeds on the ground after the seeds have fallen from the tree. In the Pine Nut Range of Nevada, deer mice, pinyon mice, Great Basin pocket mice, Panamint kangaroo rats, least chipmunk, and white-tailed antelope ground squirrel all scatter-hoard singleleaf pinyon seeds (Hollander and Vander Wall 2004; Vander Wall 1997). In one study, 1,000 labeled singleleaf pinyon seeds were placed under 5 source trees—of which 69 percent were consumed by rodents and 24 percent were scatter-hoarded 0.2–1.2 inches (5–30 mm) deep (Vander Wall 1997). Rodents placed 36 percent of these scattered caches under shrubs, 39 percent in the open, and the rest (25 percent) at the edge of shrub canopies. In a second study, all 6 of the above species harvested over 90 percent of the singleleaf pinyon seeds presented to them and scatter-hoarded from 31 percent (pocket mouse) to 66 percent (chipmunk) of the seeds they harvested (Hollander and Vander Wall 2004). Pinyon mice and deer mice distributed seeds to more cache sites (i.e., put fewer seeds in caches) than the other species and, consequently, created more potential establishment sites.

All species scatter-hoarded seeds at depths suitable for seedling emergence, but pocket mice and pinyon mice cached under shrubs more than the other species, increasing the probability of establishment. Also, in the San Francisco Mountain volcanic fields of northern Arizona, pinyon mice and brush mice placed most (70 percent) twoneedle pinyon seed caches in small-particle soil with rock cover where seeds were subject to less pilfering and had a higher probability of germination and establishment (Pearson and Theimer 2004). In a study conducted in the Pine Nut Mountains in western Nevada, rodents removed artificially cached singleleaf pinyon pine seeds more rapidly than other native seed species that included bitterbrush, desert peach, and Utah juniper (Vander Wall et al. 2019). Although most of the removed pinyon pine seeds were eaten (80 percent) and not re-cached, the new caches found were on average dispersed farther than the other three species across seasons. Pinyon pine had the largest proportion of seeds that were not recovered in both trials (74 percent), likely because seeds were taken outside of the search area.

In all of these studies, rodents were qualitatively effective seed dispersers because they buried the seeds and placed many of them in locations favorable for germination and establishment. However, many of the seeds harvested by rodents are consumed or placed in larders (large caches with high numbers of seeds), where they have little or no chance of establishment (Vander Wall 1990). From a quantitative perspective, rodents may be less important to see dispersal and establishment because, except in heavy seed crop years, most seeds do not fall to the ground before they are harvested by birds.

Less is known about dispersal of juniper species. Most species of juniper have been assumed to be dispersed largely by birds, but mammals can also disperse significant numbers of seeds. Recently it was noted that even harvester ants can carry oneseed juniper berries up to 50 feet to their nests, remove the pulp, and deposit the seeds outside their mounds (Adams and Thornburg 2010). Unlike bird dispersal of pinyon, in which the seeds are scatter-hoarded, bird dispersal of junipers is by frugivory and endozoochory, in which the seeds are ingested and passed through the gut track. At least 12 species of birds feed on fruits and potentially disperse seeds of western juniper (Maser and Gashwiler 1978), 13 species are known to disperse Ashe juniper (Chavez-Ramirez and Slack 1994), and 52 species have been observed feeding on eastern redcedar (Van Dersal 1938). Of the wide diversity of bird species involved, the most important for juniper dispersal are probably members of the highly frugivorous subfamily *Turdinae* (*Muscicapidae*) such as bluebirds, Townsend's solitaire, and American robin—and two members of the family *Bombycillidae*, the Bohemian waxwing and cedar waxwing (Chavez-Ramirez and Slack 1994; Gabrielson and Jewett 1940; Holthuijzen and Sharik 1985; Poddar and Lederer 1982; Salomonson 1978).

The rounded and more-or-less fleshy cones of junipers are well suited for frugivorous dispersal, especially by birds (Salomonson 1978; Salomonson and Balda 1977). Fruits are conspicuously colored blue or reddish and are easily accessible on the outer layers of the foliage. The fleshy portion of a juniper cone is a reasonably rich energy source. Oneseed juniper cones have an energy content of 4.57 cal/mg (Salomonson 1978), while western juniper cones have a nutritional content of 4 percent protein, 16 percent lipid, and 46 percent carbohydrate (Poddar and Lederer 1982). The thick, hard seed coat allows seeds to pass undamaged through the guts of most birds and mammals.

Despite large losses from abortion and predation, substantial fruit production can still occur. Salomonson and Balda (1977) estimated that winter feeding territories of Townsend's solitaires in northern Arizona contained about 27.2 million oneseed juniper cones per hectare in a good year and 1 million cones per hectare in the following poor year. Dispersal distances and patterns vary depending on the bird species and the juniper species (Chavez-Ramirez and Slack 1994; Holthuijzen and Sharik 1985). Birds dispersed

eastern redcedar juniper seeds to perch sites an average of 40 feet away (Holthuijzen et al. 1987), while American robins dispersed Ashe juniper seeds to perches 144 feet away (Chavez-Ramirez and Slack 1994).

The effectiveness of birds as dispersal agents varies among species of juniper. For species such as western juniper, birds appear to disperse the majority of the seeds and, thus, are quantitatively important (Lederer 1977; Poddar and Lederer 1982). Bird dispersal is often qualitatively effective as most birds deposit seeds primarily in more favorable under-shrub or tree microhabitats and only occasionally carry seeds to open microsites (Dimitri and Longland 2017). Also, seeds tend to be deposited singly or in small groups and, thus, may be less likely to die from density-dependent seed predation or competition (Chavez-Ramirez and Slack 1993; Schupp 1993). However, some bird species, such as cedar waxwings, travel in flocks and use the same perches repeatedly, resulting in high seed densities under single trees. Another limitation of bird dispersal is that seeds are deposited on the soil surface and are dependent on other mechanisms of burial (Longland and Dimitri 2016; Johnsen 1962).

Mammals have been considered to be unimportant dispersers of juniper seeds in the past but may be quite important for certain juniper species depending on the type of dispersal. Endozoochorous dispersal occurs when seed is consumed and passed through the gut. Mammals that consume and disperse juniper seeds include woodrats, Virginia opossum, Nuttall's cottontail, desert cottontail, black-tailed jackrabbit, coyote, red fox, gray fox, black bear, ringtail, racoon, mule deer, white-tailed deer, assorted livestock, and many different rodent species (Chavez-Ramirez and Slack 1993; Dimitri et al. 2017; Johnsen 1962; Longland and Dimitri 2016; Martin et al. 1951; Maser and Gashwiler 1978; Miller 1921; Parker 1945; Salomonson 1978; Schupp et al. 1997a,b; Willson 1993). All species that ingest seeds pass at least some intact seeds and, in some cases, seed germination is increased (Johnsen 1962; Miller 1921; Schupp et al. 1997a). Certain mammals that ingest seeds may be quantitatively more important in dispersing some species of juniper than others. Coyotes appear to be one of the few mammalian dispersers of western juniper (Schupp et al. 1997b), but Utah juniper appears to be dispersed more by cottontail rabbits and jackrabbits. In general, mammalian endozoochorous dispersal may not be effective for plant establishment. Seeds are deposited on the soil surface, often in high densities, and usually in the open and not in more favorable shaded environments. However, passage through the gut tract can be relatively slow, resulting in long dispersal distances.

The role of rodents likely varies among juniper species, with rodents directly dispersing junipers with drier cones such as Utah juniper and acting as secondary dispersers, removing seeds from bird and carnivore scat, in juniper species with more fleshy cones such as western juniper (Dimitri et al. 2017). Seed removal experiments of western and Utah juniper berries and seeds conducted in the spring, summer, and fall showed that the majority of seeds and berries of both species were removed in just over 2 weeks (Dimitri et al. 2017). Pinyon mice removed the most cones and seeds from all stations at both sites, so although Utah juniper berries and seeds may not be preferred by some species, such as chipmunks, juniper might be more preferred than previously thought by other rodent species.

Vander Wall et al. (2019) found conflicting evidence of low preference by rodents for Utah juniper seeds. While Utah juniper seeds were removed from artificial caches more slowly than pinyon pine and desert peach in summer and fall, and many seeds were dug up and left, the caches that were made were dispersed farther on average than desert peach and bitterbrush caches. Longer dispersal distances have previously been thought to indicate higher preference. It is likely that the mixed results are due to variation in preference or value among scatter-hoarding rodent species (Vander Wall et al. 2019).

The importance of rodent dispersal of juniper is indicated by clumps of juniper seedlings observed emerging from caches in the spring (Vander Wall 1990; 1997; Eugene Schupp, Professor, Wildland Resources/Ecology Center, Utah State University, Logan, Utah, unpublished data). In west-central Utah, a minimum of 16 to 33 percent of all naturally occurring Utah juniper recruits less than or equal to 6.6 feet tall emerged from rodent caches (Eugene Schupp, Professor, Wildland Resources/Ecology Center, Utah State University, Logan, Utah, unpublished data). Many juniper berries are husked before they are cached by rodents, likely enhancing germination and emergence (Dimitri et al. 2017). Pinyon mice and Panamint kangaroo rats husked Utah juniper seeds from cones at seed removal stations, and whole Utah juniper cones and husked seeds were found in Panamint kangaroo rat burrows (Dimitri et al. 2017).

To quantify the role of rodents in the dispersal of Utah juniper, 500 seeds (husked fruits) labeled with scandium-46 were placed under four different source trees in the Pine Nut Range, Nevada, and their fates were monitored (Stephen Vander Wall, Professor, Department of Biology, University of Nevada, Reno, unpublished data). Slightly less than half of the seeds were taken (41 percent) and of those, 27 percent were found in caches. The study was conducted in mid-summer when other, possibly more desirable, shrub and forb seeds were available.

Over the course of 21 trials using radio-labeled seeds placed under juniper canopies spread out across a western juniper site on Shinn Peak in northeastern California, 1,837 of 2,200 (83.5 percent) seeds were removed, and of those removed, 22.6 percent were cached (Dimitri et al. 2017). Pinyon mice made the most caches, placing them under juniper canopies and shrubs, and caches were generally small and shallow with an average dispersal distance of 22 feet from the source. Over 21 trials across a Utah juniper site in the Pine Nut Mountains in western Nevada, rodents removed 2,061 Utah juniper seeds from below canopies (93.7 percent), and of those removed, 22.3 percent were found in scatter-hoards (Dimitri et al. 2017). Pinyon mice again made the most caches, which were again small and shallow with most caches being found under shrub canopies at an average dispersal distance of 17.5 feet. Although Panamint kangaroo rats mostly larder-hoarded Utah juniper seeds, they made 11 caches that were found generally in open microsites with an average dispersal distance of 27.5 feet and a maximum 90 feet (Dimitri et al. 2017).

To investigate the relative roles of frugivorous birds and rodents in the dispersal of western juniper, bird and rodent removal of intact western juniper berries versus seeds cleaned either manually or by passage through birds was quantified at two northeastern California sites (Longland and Dimitri 2016). Six species of rodents were observed harvesting bird-passed and hand-cleaned western juniper seeds, including yellow-pine chipmunk, California ground squirrel, California kangaroo rat, Great Basin pocket mouse, deer mouse, and pinyon mouse (Longland and Dimitri 2016). Only California ground squirrels and deer mice were photographed taking intact juniper berries as well as seeds. All of the granivorous rodent species are scatter-hoarders, with the possible exception of California ground squirrels. Seedling emergence experiments showed that seed burial was necessary for seedling emergence (Longland and Dimitri 2016). However, emergence was significantly greater for bird-passed than for hand-cleaned seeds, which both produced significantly more seedlings than intact berries.

In general, rodents are primary dispersers of both western and Utah juniper, and because they also harvest seeds defecated by birds, they are secondary dispersers of bird-passed seeds through diplochory (Dimitri et al. 2017; Longland and Dimitri 2016; Vander Wall and Longland 2004). Rodent preference for juniper berries appears to be mixed due to variation in preference or value among scatter-hoarding rodent species. Of the seeds that are harvested, the available data indicate 20 to 25 percent are cached with the depth of

the cache—and thus likelihood of establishment—depending on the rodent species. Birds may increase seed germinability through gut passage, but many rodents husk Utah juniper berries before caching them (Dimitri et al. 2017). As described for pinyon pine, caching of bird-passed or husked juniper seeds by rodents may be highly effective as many of the seeds are placed in favorable environments and have a high potential for establishment (Dimitri et al. 2017). This may be particularly important in semiarid ecosystems.

Seedling Establishment Processes

Seed characteristics, the types of microhabitats in which seeds are placed, and growing season condition are all important in determining seed fates after dispersal. In general, pinyon pines have short-lived seeds with little innate dormancy (Meeuwig and Bassett 1983). Thus, they form only a temporary seed bank with most seeds germinating the spring following dispersal (Chambers 2001). Density of seeds in the seed bank is highly dependent on the current year's cone crop. Pinyon pines exhibit regionwide synchrony in cone production with singleleaf pinyon masting (producing cones) every 2 to 3 years and twoneedle pinyon every 5 to 7 years (Tueller and Clark 1975). The potential for a large temporary seed bank is high during mast (cone producing) years, especially since many seeds probably remain unrecovered by animals. During nonmast years, the seed bank is probably quite sparse. Germination and establishment are most likely to occur when favorable growing season conditions follow a mast year (Chambers et al. 1999a).

In contrast to pinyon pines, junipers often have long-lived seeds. Tests of stored juniper seeds showed that 45-year-old Utah juniper seed still had 17 percent germination, 21-year-old oneseed juniper had 54 percent germination, and 9-year-old alligator juniper seeds had 16 percent germination (Johnsen 1959). The long-lived seeds are often highly dormant, with germination being delayed by impermeable seed coats, immature embryos, embryo dormancy, or the presence of inhibitors (Fisher et al. 1987; Young et al. 1988). A warm stratification period, followed by a cold stratification period, results in the highest germination for Rocky Mountain juniper (Barbour and Carvalho 2009; Johnsen and Alexander 1974) and Utah juniper (Chambers, unpublished data). The frequency of large seed crops is variable among species, populations, and individuals. Despite the suggestion in the early literature that heavy seed production may occur annually in western juniper (Deal 1990), this is not the case in northeast California (Dimitri et al. 2018) or other parts of the species range in the Great Basin (Rick Miller, Professor Emeritus, Range Ecology, Oregon State University, Corvallis, Oregon, personal observation, 2018). Most species tend to produce large cone crops every 2 to 5 years and to mature smaller numbers of fruits in intervening years (Johnsen and Alexander 1974; Noble 1990). Because junipers have highly dormant seeds, and often continuous seed production, they form persistent seed banks with germination of a single seed cohort extending over many years (Chambers et al. 1999a).

Successful establishment of pinyon and juniper seedlings is generally assumed to be higher in association with a nurse plant (fig. 2-23). Most studies reporting on this phenomenon have used an observational approach and simply examined the locations of seedlings in communities with varying tree and shrub cover. Higher numbers of pinyon and juniper seedlings are typically found under shrubs or adult trees than in interspace environments (Burkhardt and Tisdale 1976; Callaway et al. 1996; Eddleman 1987; Everett et al. 1986a; Johnsen 1962). In fully stocked stands of oneseed juniper, singleleaf pinyon, and western juniper, higher number of seedlings occur under trees than in interspace environments (Everett et al. 1986a; Johnsen 1962; Miller and Rose 1995). But in areas where western juniper is expanding into sagebrush communities, higher numbers of seedlings occur under sagebrush (52 to 65 percent) than under trees (17 to 31 percent) (Everett et al. 1986a; Johnsen 1962; Miller and Rose 1995).

Figure 2-23—These singleleaf pinyons have established beneath the canopy of black sagebrush. Successful establishment of pinyon and juniper seedlings is generally assumed to be higher in association with a nurse plant. Eagan Range, Nevada. (Photo by Rick Miller, Oregon State University.)

Microhabitats under shrubs and trees have several characteristics favorable for seedling establishment. These microhabitats often have higher concentrations of limiting nutrients, higher organic matter and total nitrogen, lower bulk densities, higher infiltration and soil water holding capacities, and higher rates of nutrient cycling (Chambers 2001; Doescher et al. 1987; Everett et al. 1986b; Klopatek 1987a; Roberts and Jones 2000; Stubbs and Pyke 2005). Lower irradiance and soil temperatures also occur under shrubs and trees (Chambers 2001; Stark 1994). And although these areas receive less effective precipitation than interspace areas, they experience higher relative humidity and delayed dry down relative to open areas and grasslands (Johnsen 1962; Stark 1994; Vetaas 1992).

The few studies that have examined establishment processes indicate that nurse plants facilitate tree-seedling establishment through shading and temperature modification. Although singleleaf pinyon juveniles growing in full sun exhibit higher growth rates than those beneath shrubs (Callaway et al. 1996), growth rates in western juniper were greater beneath the shrub canopy than the interspace (Miller and Rose 1995) and Utah juniper seedlings exhibited higher survival in artificial shade (Meagher 1943). Singleleaf pinyon seedlings show higher survival under shrubs (Callaway et al. 1996; Chambers 2001), while twoneedle pinyon juveniles 1.6–39 inches tall show higher survival under shrubs in high stress environments (Sthultz et al. 2007).

High water use efficiencies and conservative growth strategies of tree seedlings may be the primary mechanisms that allow the seedlings to survive in the shaded environment under adult trees and shrubs (Nowak et al. 1999). Seedlings of western juniper have higher leaf conductance and transpiration but greater total CO_2 assimilation per unit of leaf weight than adult trees (Miller et al. 1992). Seedlings of singleleaf pinyon have higher water use efficiencies than big sagebrush nurse plants (Drivas and Everett 1988) and when growing in association with the shrub than with the shrub removed (Callaway et al. 1996).

Differences exist in the nurse plant requirement both among and within species.

Singleleaf pinyon seedlings (fig. 2-23) very rarely establish in interspaces or open environments (Callaway et al. 1996; Chambers 2001; Everett et al. 1986a). One of the few mechanistic studies of seedling establishment in pinyon and junipers showed that establishment of singleleaf pinyon was dependent upon a complex set of interacting factors including microhabitat characteristics, growing season conditions, and animal species burying the seed. Timing and rate of seedling emergence for singleleaf pinyon were temperature dependent with the order of emergence paralleling mean growing season temperatures: tree and shrub interspace was greater than under shrub, under shrub was greater than under Utah juniper, and under Utah juniper was greater than under singleleaf pinyon (Chambers 2001). Seed burial was required for rooting and the highest emergence occurred from seed burial depths of 0.4–1.2 inches (10–30 mm), which are similar to burial depths by birds and rodents.

All seedlings, including those that emerged from seeds and transplants, died within the first year in interspace microhabitats. Survival in under-tree or under-shrub microhabitats depended on soil water availability and corresponded closely to soil water contents over the three-year study. Under-shrub microhabitats had more favorable soil and microenvironmental characteristics than under-tree microhabitats and had the highest seedling life spans for the first-year seedling cohort. Predation of pinyon seedlings by rodents was a significant cause of mortality with caged transplants exhibiting life spans that were 74 percent longer overall than uncaged transplants. These results are similar to Callaway et al. 1996, except that one to two singleleaf pinyon seedlings were alive in interspaces when the study ended 3 months after seedling emergence.

The available data indicate that juniper seedlings are capable of establishing over a wider variety of microenvironmental conditions than pinyon seedlings. First-year survival of Utah juniper seedlings in the Pine Nut Range in interspace microhabitats was less than in under-tree sites but was as high, or higher, than in under sagebrush sites (Jeanne Chambers, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada, unpublished data). In Tintic Valley, Utah, emergence of Utah juniper seedlings differed among open, shrub, and tree microhabitats and also among years with no clear patterns (Eugene Schupp, Professor, Wildland Resources/Ecology Center, Utah State University, Logan, Utah and José Gomez unpublished data).

In expanding western juniper populations, 18–47 percent of established seedlings occurred in interspaces (Burkhardt and Tisdale 1976; Miller and Rose 1995). For Utah juniper on stabilized Lake Bonneville sand dunes in Utah, most of the few natural juveniles occurred in interspaces (Eugene Schupp unpublished data). Also, in the southwestern grasslands and shrublands, oneseed juniper seedlings appear to readily establish in open environments (Johnsen 1962; Salomonson 1978). Differences between pinyon and juniper in the nurse plant requirement may be related to their physiological characteristics. Juniper species have greater drought tolerance and a higher capacity to obtain water resources from interspace microhabitats and shallow soils (Nowak et al. 1999; West et al. 2008). This may enable seedlings to establish in unshaded interspaces with higher soil temperatures.

Although nurse plants facilitate seedling establishment, they also compete for available resources. A shrub manipulation experiment at Sunset Crater National Monument, northeast of Flagstaff, Arizona, found that growth and survival of juvenile pinyon trees from less than 1.6 to 39 inches (40 mm to 1 m high) growing in association with Apache plume differed in high versus low stress environments (Sthultz et al. 2007). Average mortality of juvenile twoneedle pinyon in 2002 was higher in interspaces than under shrubs in a high stress environment, but lower in interspaces than under shrubs in a low stress environment. Stem growth showed the opposite trend. Removing or tying back the shrub had a negative effect on twoneedle pinyon in a high stress environment but a

positive effect in a low stress environment. These results are consistent with Bertness and Callaway's (1994) hypothesis that as environmental stress increases, the importance of facilitation increases while the importance of competition decreases.

Higher establishment of twoneedle pinyon and juniper species in interspace environments and under higher precipitation in the Southwest is likely due to precipitation patterns. While much of the Great Basin and more northern areas receive most precipitation during winter, the Southwestern grasslands and shrublands receive a higher percentage of summer precipitation (fig. 2-1; Romme et al. 2009). Summer precipitation in the Southwest may offset the beneficial microenvironmental effects of nurse plants for seedling establishment observed in the Great Basin. This effect may be most pronounced in less stressful, higher precipitation areas.

Effects of competition from grasses and other herbaceous vegetation on pinyon and juniper seedling establishment are not clear because of the lack of experimental data. It appears that competition from annual forbs and grasses can reduce the seedling survival of Utah juniper and singleleaf pinyon during the first year after emergence (Jeanne Chambers, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada, personal observation). Also, competition from established grasses reduces the initial establishment of oneseed juniper (Salomonson 1978). However, once seedlings are established (i.e., more than 1 or 2 years old), competition appears to have little effect on subsequent survival. In western Oregon, western juniper seedlings were capable of establishing into the community regardless of grass cover or ecological condition (Miller et al. 1994).

Insects, Nonvascular Plants, and Disease Associated With Pinyon and Juniper

Although mortality of pinyon and juniper trees are often attributed to drought, mortality is usually associated with multiple factors related to drought (Shaw et al. 2005) including fire, insects, and disease. Mortality in persistent woodlands is typically low (Landis and Bailey 2005; Waichler et al. 2001), but episodic events linked to drought can result in significant die-offs of young and old pinyons and sometime junipers at local and sometimes regional levels. There are many kinds of insects, nonvascular plants, and diseases associated with pinyon and juniper (table 2-3) that can have minor to significant impacts on growth, cone and seed production, and mortality. However, the magnitude of impact is often closely related to other factors influencing tree vigor including drought, ecological site characteristics, and tree density (Furniss and Carolin 1977; Gaylord et al. 2013; Greenwood and Weisberg 2008; Negrón and Wilson 2008; Shaw et al. 2005). The extent of impact also varies at local and geographical scales (Biondi and Bradley 2013; Shaw et al. 2005). Agents of particular importance include pinyon ips or bark beetle, twig beetles, pitch moths (families *Pyralidae*, and especially *Dioryctria* spp. and *Sesiidae*), black stain root disease, and pinyon dwarf mistletoe (Hagle et al. 2003; Rogers 1993; Shaw et al. 2005).

Insects

A forest inventory in Nevada reported insects to be the largest cause of tree mortality, followed by fire (Menlove et al. 2016). They can result in significant reductions in leaf area and seed crops (Mueller et al. 2005b; see section on seed production). However, insect-caused mortality is often linked to other factors causing stress in trees, especially drought, which can result in large areas of tree mortality (Shaw et al. 2005), and pinyon cone and seed crops can be reduced by more than 90 percent (Keen 1958; Mueller et al. 2005b) (see section on seed reproduction). Juniper seed production can also be

Table 2-3—Some of the more common insects, fungi, mistletoe, and mosses associated with pinyon and/or juniper (from Bunderson et al. 1986; Burns et al. 1990; Geils et al. 2002; Hreha and Weber 1979; Jacobi and Cranshaw 2014; Rogers 1993; Shaw et al. 2005).

Common name	Scientific name	Tree	Comments
Insects			
Ips or bark beetles	*Ips confusus*	Pinyon	Considered the most important mortality agent and closely linked to drought; larva tunnel in the bole of the tree feeding on phloem.
Twig beetles	*Pityophthorus* spp. *Pityogenes* spp.	Pinyon Pinyon	Innocuous on healthy trees but can cause top-kill and mortality of drought-stressed or diseased trees.
Mountain pine beetle	*Dendroctonus ponderosae*	Pinyon	Feed on weakened trees and often reach epidemic levels during drought
Pinyon cone beetles	*Conopthorus edulis*	Pinyon	Minor to significant impact on maturing (2nd-yr) cone crops.
Juniper bark beetle	*Phloeosinus serratus*		Endemic infestations often occur during drought; adults feed on twigs and larvae on cambium.
Bark & pitch moths	*Dioryctria ponderosae* *Petrova* spp. *Sesiidae* spp. *Retinia arizonensis* *Semiothisa* spp.	Pinyon Pinyon Pinyon Pinyon Pinyon	Moth larva mine the sapwood damaging limbs, terminal shoots, and developing cones but rarely kill mature trees; trees form pitch masses at the base of limbs.
Stem-boring moth	*Dioryctria albovittella*	Pinyon	Result in stem mortality and chronic infestations can reduce seed crops > 90 percent.
Cone moth	*Eucosma bobana*	Pinyon	Reduces cone and seed crop.
Pinyon spindlegall midge Pinyon gallmidges	*Pinyonia edulicola* *Pinyonia* spp. *Janetiella* spp. *Contarinia* spp.	Pinyon Pinyon Pinyon Pinyon	Affects developing needles forming a small gall at the needle base; outbreaks typically small and short duration and rarely causes serious damage.
Pinyon sawfly	*Neodiprion edulicolus*	Pinyon	Feeds on the pinyon needles and can cause some mortality among trees < 4 ft; can result in major defoliation in local areas.
Pinyon needle miner Pinyon needle scale	*Coleotechnites edulicola* *Matsucoccus acalyptus*	Pinyon	Nymphs suck fluids from needles causing premature death of foliage; severe damage to trees usually associated with drought.
Western cedar borer	*Trachykele blondeli* *Heinrichisesa*	Juniper Juniper	Larvae extensively mine the sapwood; heavy infestations linked to stressed trees.
Juniper twig pruner	*Styloxus bicolor*	Juniper	Beetle larva mine the pith, stunting growth but damage usually minimal
Gall midge	*Walshomyia* spp.	Juniper	Common on western and Utah junipers forming artichoke-like galls.
Fungi			
Black stain root disease	*Leptographium wageneri*	Pinyon	Introduced by bark beetles and spreads belowground by contact of diseased roots with adjacent uninfected trees resulting in mort centers; ranks high as a damaging agent.
Pinyon needle rust Pinyon blister rust	*Coleosporium jonesii* *Cronartium occidentale*	Pinyon	Both rusts alternate host plants are currants and gooseberries (Ribes sp.); common in the Great Basin; symptoms are several dead branches in the crown with bark lesions (blisters) at the base
Red-belt fungus	*Fomitopsis pinicola*	Pinyon	Found in dead trees, and rarely in live trees near large wounds
Heart rot	*Phellinus pini*	Pinyon	Stem decay usually in the middle and upper portions of the trunk
Heart-rot fungi	*Antrodia juniperina*	Juniper	

(Continued)

Table 2-3—(Continued).

Common name	Scientific name	Tree	Comments
White heart-rots	*Pyrofomes demidoffii* *Diplomitoporous rimosus* *and Phellinus texanus*	Juniper Juniper Juniper	These fungi decay the heartwood core and spreads by spore dispersal infecting wounds; advanced stages can cause mortality and impacts the structural integrity of the tree; common in older trees > 200 years
Stem rust	*Gymnosporangium* spp.	Juniper	Causes brooming of foliage
Mycorrhiza			
Ectomycorrhiza Endomycorrhiza		Pinyon Juniper	Also associated with juniper
Mistletoe			
Pinyon dwarf-mistletoe	*Arceuthobium divericatum*	Pinyon	Primarily southern CA, central and southern NV and UT; can cause considerable damage increasing vulnerability to stem disease and ips; frequency and extent of occurrence increases with trunk diameter and height
Juniper mistletoe	*Phoradendron juniperunum*	Juniper	Extends across the Great Basin and Colorado Plateau infecting Utah, Rocky Mountain, and western junipers
Dense mistletoe Constricted mistletoe	*Phoradendron ligatum* *Phoradendron densum*	Juniper	Both species of mistletoe are found throughout the Intermountain West extending from Oregon into Mexico; *P. desnum* most common on western juniper
Lichens & mosses			
Wolf lichens	*Letharia columbiana* *Letharia vulpina*	Juniper	Both species commonly grow together and most abundant on dead, barkless branches, and snags

significantly reduced (Furniss and Carolin 1977; Keen 1958; Morgan and Hedlin 1960; Powell 1963). The most common groups of insects associated with pinyon and juniper that can result in stress are beetles and moths (table 2-3).

Ips (bark beetle) is considered the most important insect mortality agent in the Colorado Plateau (Hagle et al. 2003; Rogers 1993; Shaw et al. 2005). Drought is frequently associated with bark beetle outbreaks in conifers (Anderegg et al. 2015; Bentz et al. 2010; Kolb et al. 2016). Both species of pinyon pine are attacked by a variety of insect species, but pinyon ips typically cause the highest levels of mortality (Skelly and Christopherson 2003). During the severe drought between 2002–2004, a large outbreak of pinyon ips occurred across this region, resulting in 3 million acres of damaged pinyon pine (Kleinman et al. 2012). While outbreaks of pinyon ips often occur during periods of drought (Furniss and Carolin 1977; Gaylord et al. 2013; Kleinman et al. 2012), they are also associated with other factors that can stress trees, including dwarf mistletoe, root disease, and soils with low water holding capacity—less than 10 percent, typical of sandy soils (McMillin et al. 2008; Negrón and Wilson 2003; Peterman et al. 2013; Shaw et al. 2005). Beetle populations and levels of mortality return to endemic levels when more normal precipitation amounts return (Kolb et al. 2016; Meddens et al. 2015).

Studies of pinyon ips outbreaks show that levels of mortality are linked to tree size, drought, increased winds, and pathogens such as black stain root disease and pinyon dwarf mistletoe (Hessburg et al. 1995; Meddens et al. 2015; Negrón and Wilson 2003; Wilson and Tkacz 1992). However, studies disagree on the importance of stand density, elevation, soil characteristics, and absence of a previous disturbance in supporting outbreaks (Meddens et al. 2015). These disagreements may be due to differences in how different scientists define drought severity or duration and whether the most affected trees have colonized marginal sites during periods of highly favorable growing conditions (Greenwood and Weisberg

2008; Meddens et al. 2015). Under exceptional drought conditions, as occurred in the early 2000s, the top-down climate influence may simply override the effects of bottom-up factors such as stand density, elevation, and soil characteristics.

Defining the climate factors conducive to pinyon ips outbreaks has been difficult due to inconsistent definitions of drought severity and duration—and often a lack of drought condition description in the various studies (Meddens et al. 2015). Pinyon ips can produce two to five generations per year, depending on climate (Eager 1999; Skelly and Christopherson 2003), but none of the descriptions found describe what thresholds govern how many generations may occur. Since temperature is a significant control on insect development and activity, there are likely fewer generations where overall temperatures are lower. As temperatures increase under climate change, pinyon ips may produce more generations per year and more adults will survive overwintering (Anderegg et al. 2015; Meddens et al. 2015; Negrón and Wilson 2003), potentially leading to greater impacts to singleleaf pinyon than have been documented thus far.

Gaylord et al. (2013) determined that 1 or more years of precipitation at only 55 percent of average favored successful pinyon ips attack and 3 years of precipitation at that level resulted in significant reductions of resin duct size and number and in 70 percent mortality of mature trees. Resin is an important insect inhibitor. Wilson and Tkacz (1992) found that the risk of twoneedle pinyon mortality from pinyon ips attack increased when April through July precipitation was less than or equal to 75 percent of average, based on a more localized outbreak in 1990 and 1991. Twoneedle pinyon's reliance on summer precipitation when temperatures are highest during the year may also result in greater vulnerability to pinyon ips attack than singleleaf pinyon.

Nonvascular Plants: Fungi

Although there are numerous species of fungi associated with pinyon and juniper (table 2-3), black stain root disease, which infects pinyon, is considered one of the most serious fungal-damaging diseases in the West. It has been related to extensive mortality in southwest Colorado and southeast Utah (Shaw et al. 2005). The primary vector of infection is through root contact between infected and uninfected trees (Skelly and Christopherson 2003), resulting in dead patches or mosaics of trees (Kearns and Jacobi 2005). It is also spread by root-feeding beetles. This fungal pathogen infects water-conducting root and stem tissue, preventing water movement to leaf-foliage (Hagle et al. 2003; Shaw et al. 2005). It kills young trees within 1–2 years (Skelly and Christopherson 2003). However, older trees decline more slowly, becoming increasingly susceptible to drought and insect infestation.

Pinyon blister rust, closely related to white pine blister rust, is also common across the Great Basin and Colorado Plateau. Although seldom resulting in mortality, the stressed trees are more susceptible to ips. Heart-rots are also widely spread throughout both pinyon and juniper across the Great Basin and Colorado Plateau. Heart-rots are primarily found in older trees, particularly in old-growth stands (fig. 2-24). Affecting primarily the heartwood in the trunk and large limbs, these rots rarely directly kill the tree, but can structurally weaken them. There was a widespread occurrence of heart rot in western juniper around 1730, attributed to possible climatic conditions (Knapp and Soulé 1999). Stem rust also has been reported to frequently occur in Utah juniper (Bunderson et al. 1986).

Nonvascular Plants: Mycorrhizal Fungi

Mycorrhizae are thought to increase the availability of water and nutrients to host plants, especially in nutrient-poor soils (Meyer 1973). However, the importance of these fungi can vary with soil drying patterns, soil pore structure, and number of hyphal connections extending from the root into the soil (Allen 2007). Mycorrhizae populations

Figure 2-24—The outer-most band of heart rot on this tree occurred between 1750 and 1730. This band of heart rot is widespread across the range of western juniper and is attributed to a climatic event or conditions. (Photo by Rick Miller, Oregon State University.)

are also influenced by drought, insects, mistletoe, and competition (Gehring et al. 2014; Sthultz et al. 2007; Swaty et al. 2004; Vecchio et al. 1993). Pinyons and junipers form mycorrhizal associations that, at least for pinyons, are positively linked to both seedling and adult plant growth (Gehring and Whitham 1994; Swaty et al. 2004). Pinyons are often the only associate of ectomycorrhizal (EM) in woodland communities, which do not penetrate the host's root cells but form an intercellular interface consisting of highly branched hyphae—long, branching filamentous structures of fungus (table 2-3).

Juniper are primarily associated with endomycorrhizal fungi (arbuscular mycorrhizal or AM), which penetrate the cortical cells of the roots of a vascular plant (Reinsvold and Reeves 1986). However, Utah juniper was reported to be infected with both AM and EM in northern Arizona (Klopatek and Klopatek 1987; Reinsvold and Reeves 1986). Although there are thousands of EM species, woodland communities in northern Arizona were dominated by one or a few types (Gehring et al. 1998). In juniper dominant or pinyon and juniper codominant woodlands, AM was significantly more abundant than EM (Haskins and Gehring 2005).

Nonvascular Plants: Lichens and Mosses

Two species of foliose lichens commonly associated with semiarid conifers are *Letharia columbiana* and *L. vulpine* (fig. 2-25a,b; Miller et al. 2005). These lichens are brilliant fluorescent yellow-green or chartreuse in color and highly branched. Both species are nearly identical in form except that *L. vulpina* lacks the small disk-like fruiting bodies (soredia). Both species can occur on a single tree and are often most abundant on dead, barkless branches or snags. *Lethari columbiana* is widely spread throughout the Intermountain West, whereas *L. vulpina* is primarily limited to the Northwest and northern Rocky Mountains.

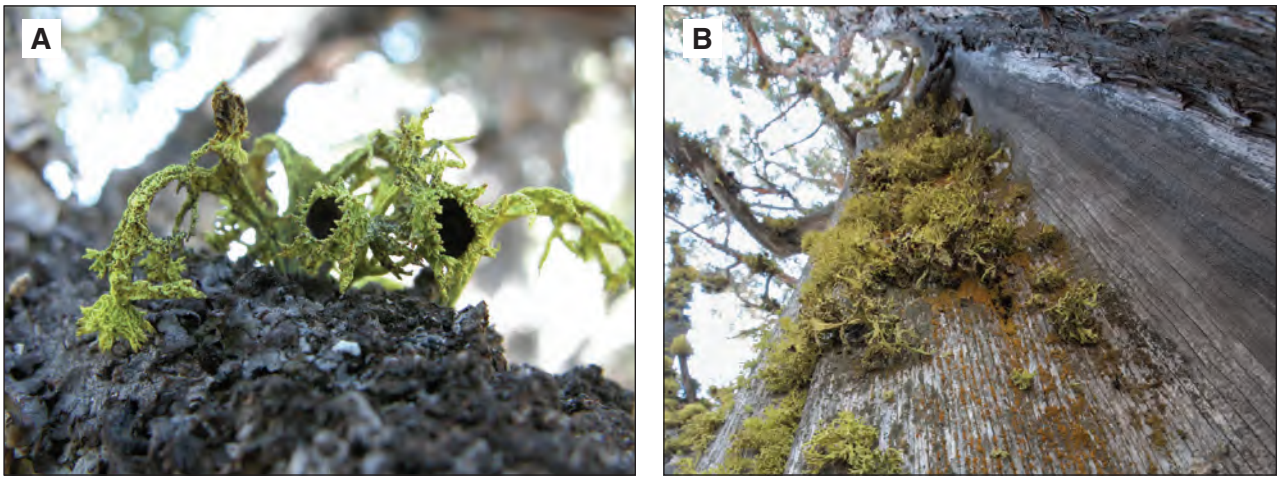

Figure 2-25—*Letharia columbiana* and *L. vulpina* are two species of foliose lichens commonly associated with semiarid conifers. (A) *L. columbiana* is widely spread throughout the Intermountain West and contains small disk-like fruiting bodies. (B) Both species of lichens are growing on the trunk of this tree. *L. vulpine* (on the lower left) primarily occurs in the northwest and lack the disk-like fruiting bodies. (Photos by Rick Miller, Oregon State University.)

Figure 2-26—Juniper mistletoe (shown here) and constricted mistletoe are the most common species infecting juniper in the Intermountain Region from Oregon southward into Mexico. Panamint Range, California. (Photo by Rick Miller, Oregon State University.)

Mistletoe

Several species of mistletoe commonly occur on juniper and pinyon across the West. Juniper mistletoe and constricted mistletoe are the most common species infecting juniper in the Intermountain region from Oregon south into Mexico (fig. 2-26). Their sticky seeds are primarily dispersed by birds, including American robins, Townsend's solitaires, cedar waxwings, flycatchers, and mountain bluebirds (Gill 1990; Sutton 1951). Seeds are also dispersed by wind and gravity, making dense stands more susceptible to infestation (Geils et al. 2002). Distribution among trees is often patchy with some heavily infested.

Pinyon dwarf mistletoe is restricted to pinyon species in the Intermountain regions south into Mexico and east into southwest Texas. It is considered a more serious conifer problem than leafy mistletoe in that it causes a higher incidence of mortality (Hreha and Weber 1979). In addition to increasing stress through high demands for water and nitrogen from its host, pinyon dwarf mistletoe also increases the potential for infestations by ips and stem diseases (Geils et al. 2002). Infestation was found to be directly related to increasing tree density and size (Hreha and Weber 1979). The mechanism for dwarf mistletoe seed dispersal, unlike the leafy mistletoe species, is primarily by its explosive discharge of seed (Geils et al. 2002). This frequently results in a clustered distribution of infected trees. However, birds and mammals are also important for long-distance dispersal.

Overstory/Understory Relationships

Sidebar 2

Space Versus Time

Numerous studies evaluate woodland succession in the Great Basin and Colorado Plateau. However, our understanding of succession comes largely from studies substituting space for time, where different locations (space) with different time-since-disturbance are compared. When space is substituted for time, it is critical to consider all of the key components (fig. 2-29) as to how they compare across the different locations. Only a few studies have measured vegetation change over time at the same location and are largely short-term (less than 10 years) (Miller et al. 2013), with few extending 20 to 42 years (Bates et al. 2017b; Bristow et al. 2014; Schaefer et al. 2003), and none we could find extending past 50 years.

Succession

There is strong evidence supporting the inverse relationship between the tree overstory and understory vegetation, resulting in a successional gradient of changing woodland structure and composition (see Appendix B, sidebar 2) as trees become dominant. However, there is considerable variation in the rate of woodland development (fig. 2-27) and the relationship of its effects on understory vegetation (fig. 2-28; Johnson and Miller 2006; Roundy et al. 2014a). Variation in stand structure, composition, and rate of woodland development are largely determined by the key components of the ecological site (fig. 2-29), which vary considerably at multiple scales across the Great Basin and Colorado Plateau.

Early work described the successional stages following a stand-replacement fire in pinyon and juniper woodlands (Barney and Frischknecht 1974; Erdman 1970). Stages of succession included annual and/or perennial herbaceous vegetation transitioning to an herbaceous-shrub mix, followed by an increasing dominance of trees and decline in shrubs, grasses, and forbs (figs. 2-30, 2-31). More recent work supports this general sequence of succession following a stand-replacement event, although the potential for the persistence of invasive annuals creating an alternate steady state following a stand-replacement disturbance is of concern (Everett and Ward 1984; Miller and Heyerdahl 2008; Stringham et al. 2015a,b; Wangler and Minnich 1996).

Herbaceous Succession

The presence and persistence of an early annual herbaceous phase is dependent on the understory composition prior to the disturbance, soil moisture and temperature regimes, seasonal soil moisture and temperature, and the type and severity of disturbance, such as a low-, moderate-, or high-severity fire (Miller et al. 2013, 2014a; Roundy et al. 2018). In low- to moderate-severity fires, the postfire response of herbaceous cover and biomass are closely related to prefire plant composition (fig. 2-32; Allen et al. 2008b; Bates et al. 2014a; Dhaemers 2006; Koniak and Everett 1982; Miller et al. 2013). This is also usually true with other disturbances, resulting in mortality of the tree overstory with little to no impact on the understory such as mechanical tree reduction (Everett and Sharrow 1985a; Miller et al. 2014b; Roundy et al. 2014a). However, high-severity fires, which are characteristic of wildfires in late Phase II and III woodlands, usually result in more than 85 percent mortality of perennial grasses (Bates et al. 2011) and can consume 85–98 percent of the seed bank (fig. 2-33; Beckstead et al. 2011). These high-severity events can promote the dominance of invasive annuals, which may shift the plant community to an annual steady state (Appendix C; Bates et al. 2014a; Stringham et al. 2015a,b; Tausch 1999).

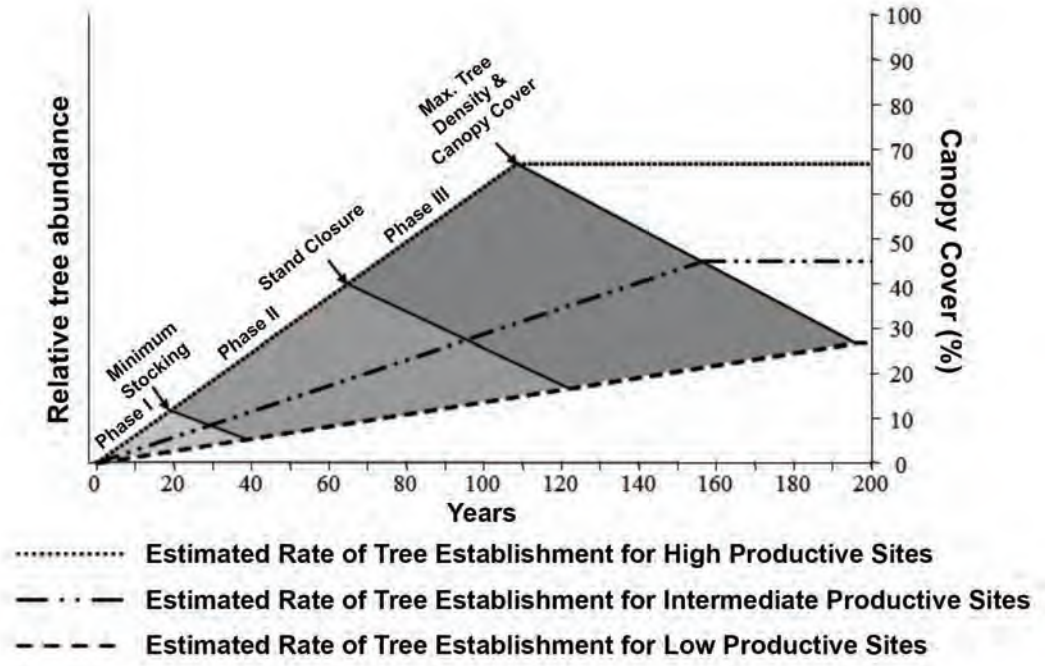

Figure 2-27—Hypothesized amount of time required from initial western juniper establishment (early Phase I) to a minimum stocking level for stand closure (early Phase III), and estimated maximum potential for tree density and cover as related to site productivity (from Johnson and Miller 2006). Projected rates of closure are similar for pinyon pine and Utah juniper (from Tausch et al. 2009).

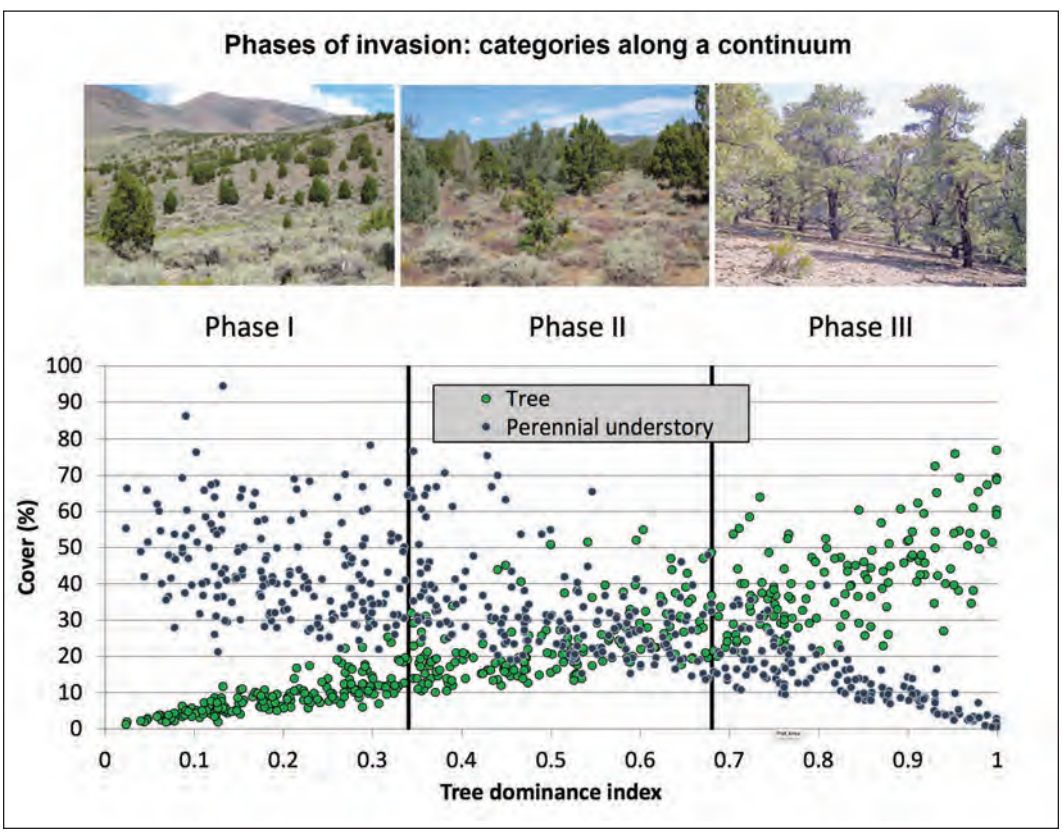

Figure 2-28—Changes in perennial understory cover and tree dominance (tree cover/[tree+shrub+tall perennial grass cover]) for 11 Great Basin sagebrush steppe sites ranging from Phase I to Phase III pinyon-juniper (see Glossary for full definitions of Phase and TDI). The wide variation is largely a result of ecological site attributes (Roundy et al. 2014a).

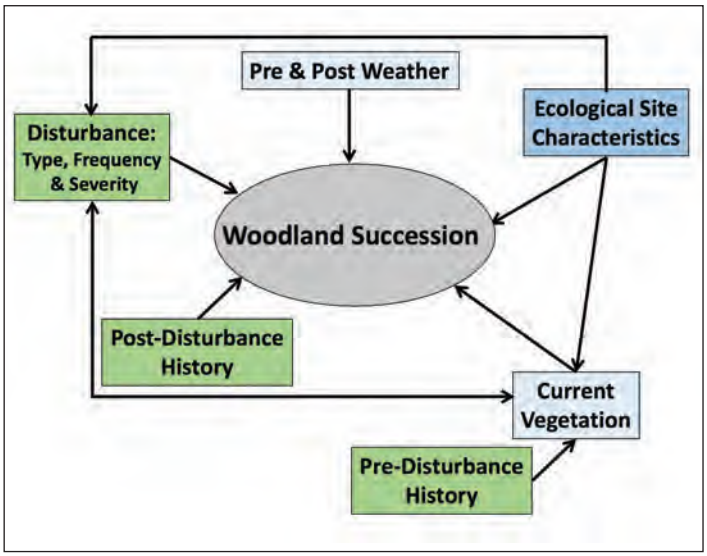

Figure 2-29—A simple conceptual model of the key components affecting postdisturbance woodland succession. Ecological site characteristics relate to climate, topography, and soils. Weather is the atmospheric condition occurring during the time-period of interest.

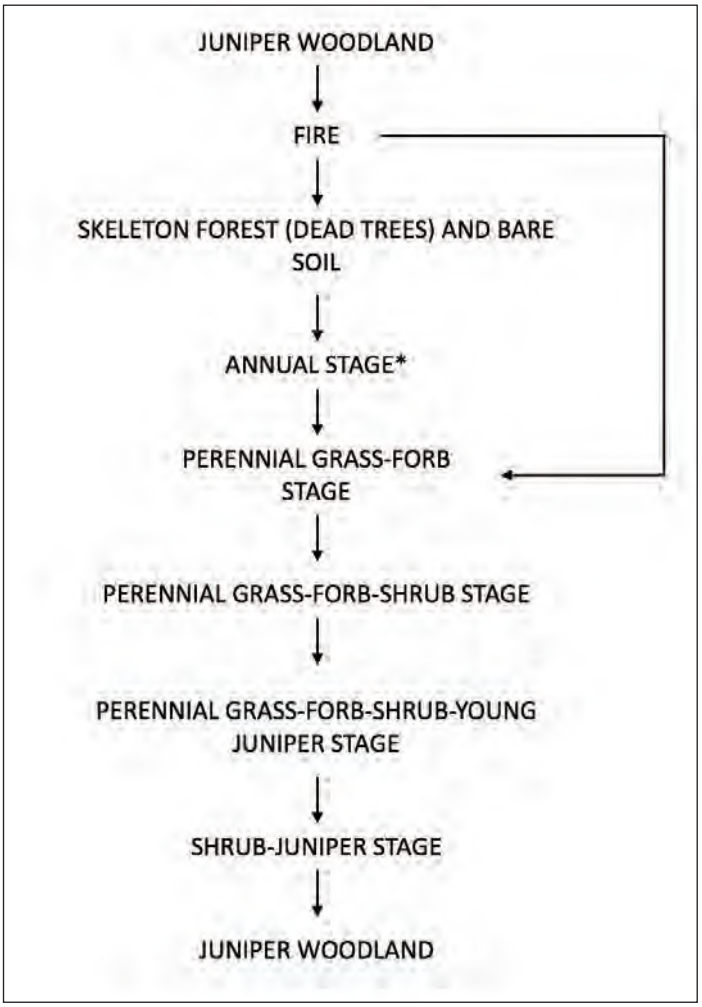

Figure 2-30—Suggested successional stages after fire in pinyon and juniper woodlands. Plant annual stage during early succession may be bypassed if a perennial understory is present prior to and persists following fire. (From Erdman 1970; Barney and Frischknecht 1974.)

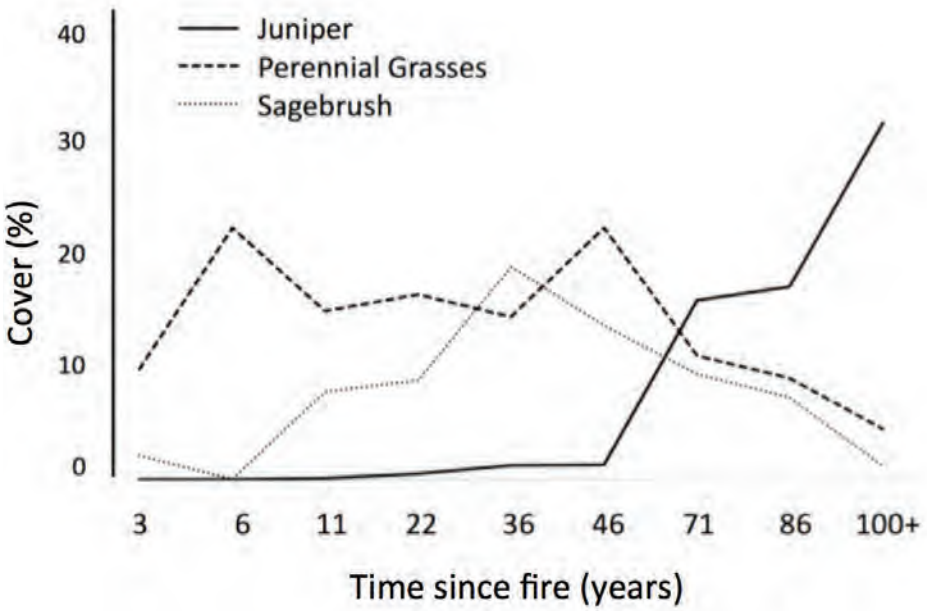

Figure 2-31—Surface cover of juniper, perennial grasses, and sagebrush by approximate time since fire (derived from Barney and Frishknecht 1974).

Figure 2-32—Following a moderate severity fire (note browned conifer needles remaining on trees), herbaceous response in the first growing season was primarily from residual perennial grasses (present prior to the fire). Sagebrush mortality was high—a result of both the fire and a prior infestation of Aroga moth in the area. Central Oregon. (Photo by Rick Miller, Oregon State University.)

Figure 2-33—Following a high severity fire, herbaceous response in the first growing season was primarily native annual forbs. Although the high severity fire could have resulted in high mortality of native perennial grasses, the lack of burned grass crowns near the soil surface indicates understory vegetation was likely severely depleted prior to the fire. The resistance of this site to invasive annual grasses is very low (lack of perennial herbs and warm and dry soils), resulting in the potential of large increases of invasives in the second and third year following fire. Central Utah. (Photo by Rick Miller, Oregon State University.)

Sequences of plant composition during succession after a stand-replacement event follows a general pattern (figs. 2-30, 2-31), but duration of each sequence can vary widely. If there is a native annual forb response, it is typically short-lived, persisting less than 5 years postfire (Barney and Frischknecht 1974; Bates et al. 2017a,b; Dhaemers 2006; Everett and Ward 1984; Koniak 1985). Perennial forb abundance is also inversely influenced by tree canopy dominance (Roundy et al. 2014a) and usually increases following a stand-replacement event reaching a peak within the first 2–5 years (Bates et al. 2017b; Everett and Ward 1984; Miller et al. 2014b) then declining to preburn levels (Bates et al. 2017b). Perennial grasses commonly peak in abundance within the first 10 years, followed by a decline and leveling off during the next 10 to 45 years, then declining with increasing tree dominance to less than 5 percent cover (fig. 2-34; Bates et al. 2017b; Miller and Heyerdahl 2008). However, perennial grasses may persist at relatively high levels of abundance in the late stages of woodland development on deep loamy soils and where grasses have not been overgrazed (fig. 2-35; Miller et al. 2005).

Shrub Succession

There is a very strong inverse relationship between the abundance of pinyon and juniper and with understory shrubs (fig. 2-36; Barney and Frischknecht 1974; Bybee et al. 2016; McHugh and Gehring 2006; Roundy et al. 2014a; Williams et. al 2017), although it varies across different ecological sites, plant associations, and shrub species (figs. 2-34, 2-35, 2-37; Miller et al. 2000). Sagebrush appears to be one of the most sensitive shrubs to increasing tree dominance, declining at more rapid rates than bitterbrush. Following a stand-replacement event, the shrub phase typically increases and peaks 30 to 50 years, followed by a decline with increasing tree dominance (fig. 2-31;

Figure 2-34—This closed Phase III pinyon and juniper woodland is approaching full dominance by the tree overstory. The lack of deep-rooted perennial grasses is the result of either tree competition, past poor grazing management, or both. Shrubs are also nearly absent, except for in the few openings, such as shown in the foreground, and sapling trees have limited annual growth. Grand Staircase, Utah. (Photo by Rick Miller, Oregon State University.)

Figure 2-35—Shrub skeletons are the only evidence that shrubs once occurred before trees dominated the site. However, the moderately deep to deep soils allow deep-rooted perennial grasses to persist under proper management in this Phase III pinyon and juniper woodland. Southern Utah. (Photo by Rick Miller, Oregon State University.)

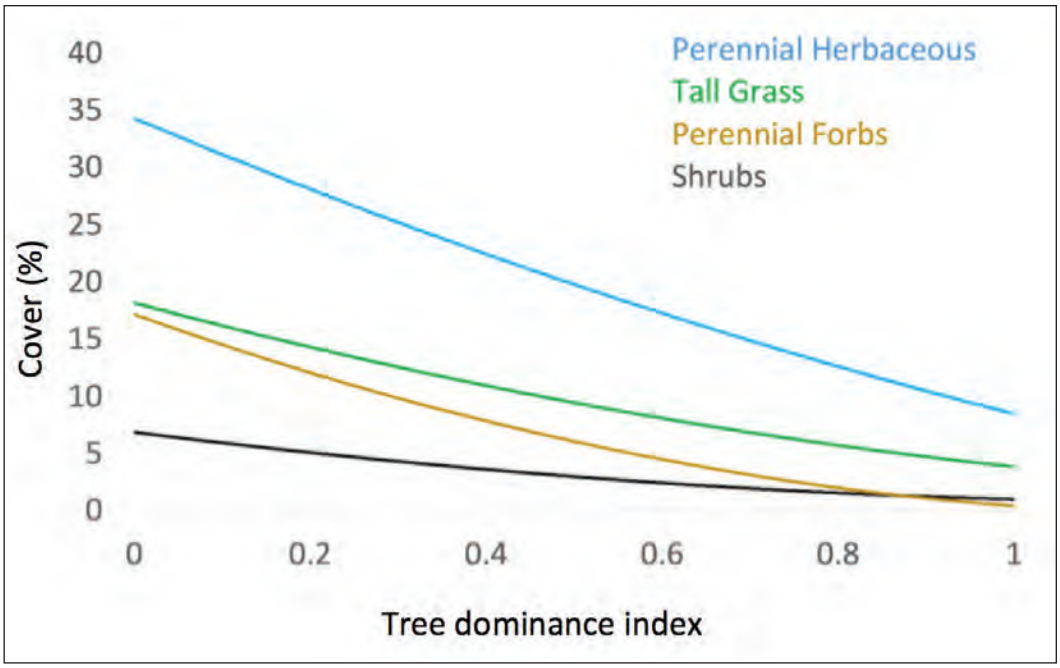

Figure 2-36—Understory vegetation cover in relation to increasing tree dominance index (TDI; see Glossary for full definition) (derived from Roundy et al. 2014a).

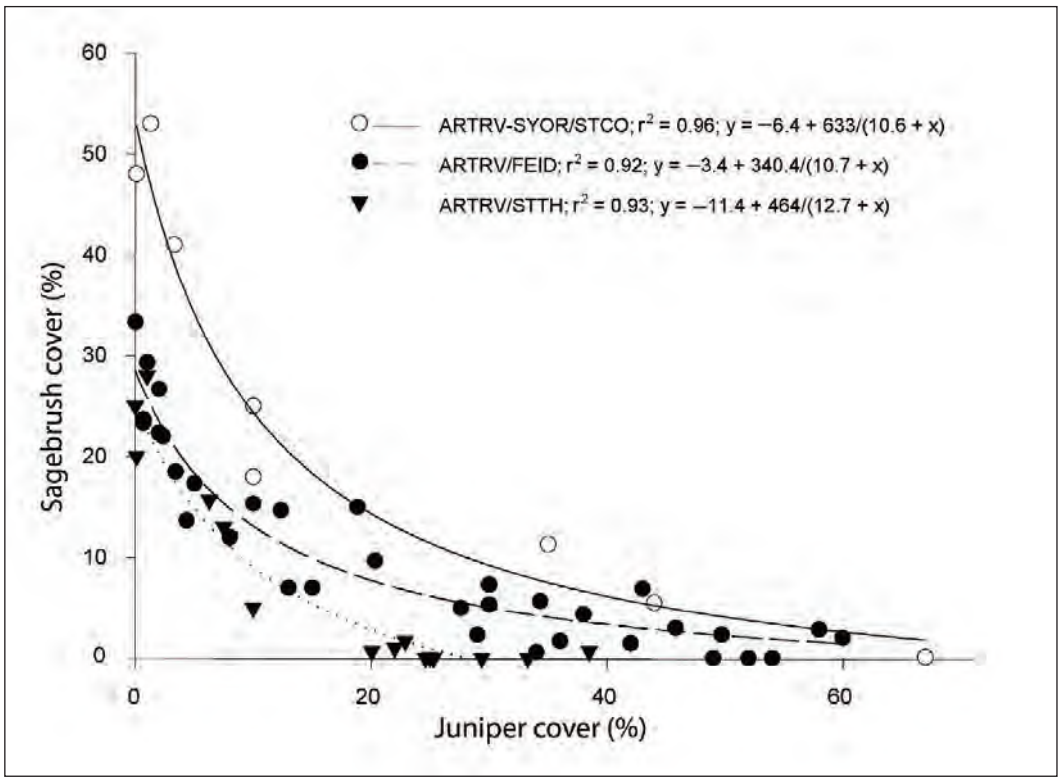

Figure 2-37—Relationship between juniper and sagebrush cover for the mountain big sagebrush/ Thurber needlegrass (ARTRV/STTH), mountain big sagebrush/ Idaho fescue (ARTRV/FEID), and mountain big sagebrush-snowberry/Columbia needlegrass (ARTRV-SYOR/STCO) associations. The more productive sites (Columbia needlegrass > Idaho fescue > Thurber needlegrass) show a higher level of juniper cover in relation to existing sagebrush cover (Miller et al. 2000).

Barney and Frishknecht 1972; Bybee et al. 2016; Miller et al. 2000; Roundy et al. 2014a; Schaefer et al. 2003; Tress and Klopatek 1987; Wangler and Minnich 1996; 2005).

However, the recovery of the shrub layer is dependent on seed availability for nonsprouting shrubs (e.g. sagebrush and bitterbrush, which is a weak resprouter) and the prefire density of sprouting shrubs—including green and grey rabbitbrush, horsebrush, and snakeweed. Mountain big sagebrush canopy cover usually approaches 20 to 30 percent within 20 to 35 years postfire—but can take up to 50 years or less than 20 years in small patchy burns (Bunting et al. 1987; Lesica et al. 2007; Miller and Heyerdahl 2008; Moffet et al. 2015; Nelson et al. 2014; Ziegenhagen 2003; Ziegenhagen and Miller 2009). The ability of bitterbrush to resprout is highly variable, and this plant is typically a weak resprouter in more arid environments (Miller et al. 2013).

Postfire reestablishment of bitterbrush in mountain big sagebrush communities followed a similar pattern to mountain big sagebrush and came largely from seed (Ziegenhagen and Miller 2009). Recovery of Wyoming and black sagebrush, which occur on drier and/or warmer sites and low sagebrush occurring on shallow to very shallow often heavy clay soils, are often considerably slower than mountain big sagebrush (Hosten and West 1994; Rhodes et al. 2010). Sprouting shrubs such as snakeweed and green rabbitbrush will reestablish and peak 10 to 12 years postfire—often followed by a decline (Harniss and Murray 1973; Rhodes et al. 2010; Wangler and Minnich 1996; Young and Evans 1974). However, these relatively shorter-lived species compared to sagebrush can persist at relatively high levels for up to 40 years (Barney and Frischknecht 1974) under regimes of frequent disturbance (Young and Evans 1974).

Tree Succession

Many studies have reported low tree dominance 45 years after a stand-replacement disturbance, followed by a rapid expansion in tree canopy cover (fig. 2-31; Barney and Frischknecht 1974; Miller et al. 2005; Miller and Tausch 2001; Tausch and West 1988; Tress and Klopatek 1987; Wangler and Minnich 1996). Timing and rate of tree-seedling establishment following a stand-replacement disturbance is a primary factor determining the rate of tree canopy development. Postdisturbance tree establishment is dependent upon seed source, dependent upon resource availability, and enhanced by the presence of a shrub canopy, which provides a more suitable environment for young trees—see nurse plants in seedling establishment processes section (Everett et al. 1986a; Johnsen 1962; Miller and Rose 1995; Wangler and Minnich 1996).

Once established, the growth rate of tree seedlings is relatively slow (Miller et al. 2005, 2007; Tausch et al. 2009). However, once trees reach 40 to 50 years of age, the rate of canopy expansion typically increases, although the rate of growth varies with site productivity. The presence of mature trees surviving a stand-replacement event can also more rapidly initiate the development of woodlands compared to stands lacking trees (Johnson and Miller 2008). During the late stages of tree canopy development, establishment and growth of understory trees is suppressed by the mature overstory trees (Miller et al. 2000). In addition, intraspecific competition among trees in late woodland development results in the reduction of tree branch leader growth and cone production (fig. 2-38).

Where ecological site conditions are suitable for both juniper and pinyon species, reestablishment of juniper frequently precedes pinyon after a stand-replacement event, followed by an increasing rate of pinyon establishment that often eventually exceeds that of juniper (Huffman et al. 2012; Tausch and West 1988; Wangler and Minnich 1996; Woodbury 1947). In late Phase II and III woodlands, the relative canopy cover of understory pinyon trees compared to juniper is often greater than in the overstory canopy (Abella et al. 2012). Changes in vegetation structure during succession modify microsites

Figure 2-38—Leader growth on these tree saplings indicate that: (1) this ecological site is relatively productive; (2) there is little intraspecific competition among trees; and (3) the shrub layer has little effect on tree growth. Although leader growth is shorter on less productive sites, the length of leaders on younger trees becomes severely reduced under intraspecific competition from the tree overstory, indicating a near closed stand of trees. Grand Staircase, Utah. (Photo by Rick Miller, Oregon State University.)

for seedling establishment and may be more beneficial for pinyon over time. Pinyon is more sensitive to dry soil conditions then juniper, shutting down photosynthesis and resulting in a disadvantage under droughty conditions (Barnes and Cunningham 1987; Breshears et al. 1997a).

There is likely significant competition for limited soil resources between pinyon pine and juniper (Haskins and Gehring 2004). Reduction of juniper roots results in a near twofold increase of pinyon roots and ectomycorrhizal associated with pinyon. Also, the establishment of juniper in Arizona was reported to be related to time since fire, while pinyon appeared to be more episodic, related to climate conditions (Huffman et al. 2012). But in Mesa Verde, Colorado, differences in initial establishment following a stand-replacing fire between juniper and pinyon were not clear (Erdman 1970).

Expansion of pinyon and juniper into meadows, riparian areas, and aspen has also been reported in the Intermountain West. Singleleaf pinyon and Utah juniper expanded into riparian and meadow communities following down-cutting of deep meadow soils in southwest Utah (Cottam and Stewart 1940) and western juniper into aspen communities across the northwest Great Basin (Wall et al. 2001). These conversions were attributed to improper grazing and/or browsing, and lack of fire.

Succession to Old-Growth

Old-growth pinyon and juniper woodlands are the late stages of succession with distinct characteristics that evolve over centuries. Intervals between stand-replacement events in these old-growth woodlands are hundreds of years (sidebar 3), allowing trees to attain ages of many centuries and woodlands to develop old-growth characteristics. Old growth is typically defined at the community level and encompasses the later stages of woodland or forest development that typically differs from earlier stages in a variety of characteristics, which include tree age and size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function (Kaufmann et al. 1992; USDA Forest Service 1993). Characteristics of old-growth pinyon and juniper woodlands vary widely across the Great Basin and Colorado Plateau (Kaufmann et al. 1992; Miller et al. 1999). The majority of old-growth woodlands are composed of old trees (more than 250 years) and the accumulation of large dead wood comprising snags, logs, and weathered stumps (table 2-4; Floyd et al. 2003; Miller et al. 1999, 2007, 2014a; Tausch et al. 2009; Waichler et al. 2001).

Characteristics of individual old pinyon and juniper trees compared to younger mature trees include differences in tree canopy shape, distinct bark characteristics including strips of shaggy bark and distinct vertical furrows, rot pockets, cavities, and branch structure, which may include large basal branches, and dead branches often covered with lichen (fig. 2-39a,b,c). These morphological characteristics commonly begin to develop between 150 and 200 years and become more developed over time (Miller et al. 1999). Utah and western juniper can exceed ages of 1,500 years, and pinyon over 900 years (Miller et al. 2005, 1999; Strachan and Biondi 2013; Swetnam and Brown 1992; Tausch et al. 1981). The oldest of the old pinyon and juniper are usually found on the harshest sites where there is little surface fuel and growth is slow, resulting in changes in wood structure and chemistry (Farjon 2010; Swetnam and Brown 1992; Christopher Baisan, Retired Dendrochronologist, Dendrochronology Laboratory, University of Arizona, Tucson, Arizona, personal communication, 1991). In the Southwest, pinyon and juniper woodlands older than 400 years are comparatively rare, possibly a result of severe drought in the late 1500s causing high tree mortality (Swetnam and Brown 1992). Following the drought, there was a substantial increase in tree establishment, beginning in the early 1600s that peaked around 1700.

As described in the soils section in more detail, old-growth woodlands are often associated with rock outcrops, knolls, ridges, and/or soils that are shallow, coarse, rocky, and often high in clay or sand (fig. 2-40; Barney and Frischknecht 1974; Bauer and Weisberg 2009; 1974; Cottam and Stewart 1940; Emerson 1932; Holmes et al. 1986; Miller and Rose 1999; Nicol 1937; Stringham et al. 2015; Woodbury 1947). But there is considerable variation in ecological site characteristics, which contributes to the wide variation in woodland structure and species composition on sites where persistent woodlands can occur. Old-growth pinyon and juniper woodlands can be grouped into three broad community types, which include woodland, juniper-low sagebrush tableland, and pinyon and juniper savanna (Miller et al. 1999).

Sidebar 3

Old-Growth, Persistent, and Presettlement Woodlands

In the literature, the terms presettlement, persistent, and old-growth are often used for woodlands existing on the landscape prior to Eurasian settlement. Although often used interchangeably, each has a different meaning and may or may not be one and the same. Presettlement woodlands established prior to Eurasian settlement and introduction of livestock around the 1860s may or may not exhibit old-growth characteristics. Persistent woodlands (synonymous with potential vegetation) are based on ecological site characteristics and disturbance regimes that allow woodlands to develop into a late successional stage. Old-growth is based on relative tree age and woodland structural characteristics. See Glossary for complete definitions.

Scattered old trees can also occur in shrub or grass dominated communities, often associated with microtopography (fig. 2-41). Established woodlands typically have more than 20 percent tree canopy cover with little to substantial perennial herbaceous understory and limited to no shrub layer. The abundance of the perennial herbaceous layer is largely attributed to soil characteristics, especially soil depth, disturbance regimes, and tree density (fig. 2-42; Miller et al. 2005; Swetnam and Brown 1992). Juniper-low sagebrush tableland occurs on very shallow soils over fractured basalt or claypans (most common in the western juniper region). It usually has less than 10 percent tree canopy cover and an understory of low sagebrush and Sandberg bluegrass (fig. 2-43). Pinyon and juniper savanna, most common in the Colorado Plateau, typically has less than 10 percent canopy cover with a predominant perennial grass understory (fig. 2-44).

In all three old-growth types, there has been significant infill throughout the Great Basin and Colorado Plateau, which started around 1900 and is attributed to (or a combination of) climate, grazing, and altered fire regimes (see Section 3). In addition to these three general types, scattered patches of old trees commonly occur on rock outcrops, knolls, and ridges across the landscape. Observations of Arizona savannas and grasslands in the early 1900s reported old pinyon and juniper seed trees occupying the rocky knolls and ridges adjacent to the grasslands (Leopold 1924; Nicol 1937).

Table 2-4—Characteristics that differentiate young and old-growth woodlands. There are several types of woodlands based on stand age in the Great Basin and Columbia River Plateau region. These include: (1) old-growth woodland; (2) woodlands that were formerly old growth, but are currently occupied by young trees (less than 150 years old) as a result of a stand replacing disturbance; (3) tree shrub savanna where the old trees are less than 10 percent canopy cover; (4) tree shrub savanna that is infilled by post-settlement young trees; and (5) sagebrush shrub-steppe occupied by young trees (less than 150 years) (modified from Miller et al. 2007 and Tausch et al. 2009).

Woodland characteristics and tree growth form		
Characteristic	**Postsettlement trees**	**Presettlement trees**
Juniper crown shape	Conical with point tip	Flattened, rounded, or uneven tops
Piñon crown shape	Conical with pointed to slightly rounded tip	Flattened, rounded, or uneven top
Juniper branch structure	Branches get progressively smaller from bottom to top of tree	In open stands, large branches near the base
Piñon branch structure	Branches become smaller from bottom to top of tree, general orientation is vertical	In open stands branches large near base and remain relatively large well into the crown, more randomly oriented
Juniper bark	Flaky, relatively thin with limited or shallow vertical furrows	Thick, fibrous with well-developed vertical furrows
Piñon bark	Relatively thin, flaky, with weak vertical furrows	Thicker, more plate-like structure than furrowed
Juniper leader growth	Terminal leader growth in the upper 1/4 of the tree usually > 2 in. In open stands, leader growth > 2 in from bottom to top	Leader growth in the upper 1/4 of the tree usually < 1 in
Piñon leader growth	Leader growth in pinyon similar to juniper but not directly visible; must look for bud scale scares to determine length	Leader growth in upper 1/4 of the tree usually < 2 in.
Tree canopy lichen	Little or no foliose lichen on juniper	Juniper often covered by bright green foliose lichen
Dead wood in standing tree	Little dead wood in bole, few to no dead trees, logs, or large stumps	Dead branches, bark missing, black stain and/or black lichen
Large wood across the site	Large diameter logs and stumps absent	Large diameter logs and stumps, often charred, scattered across the site

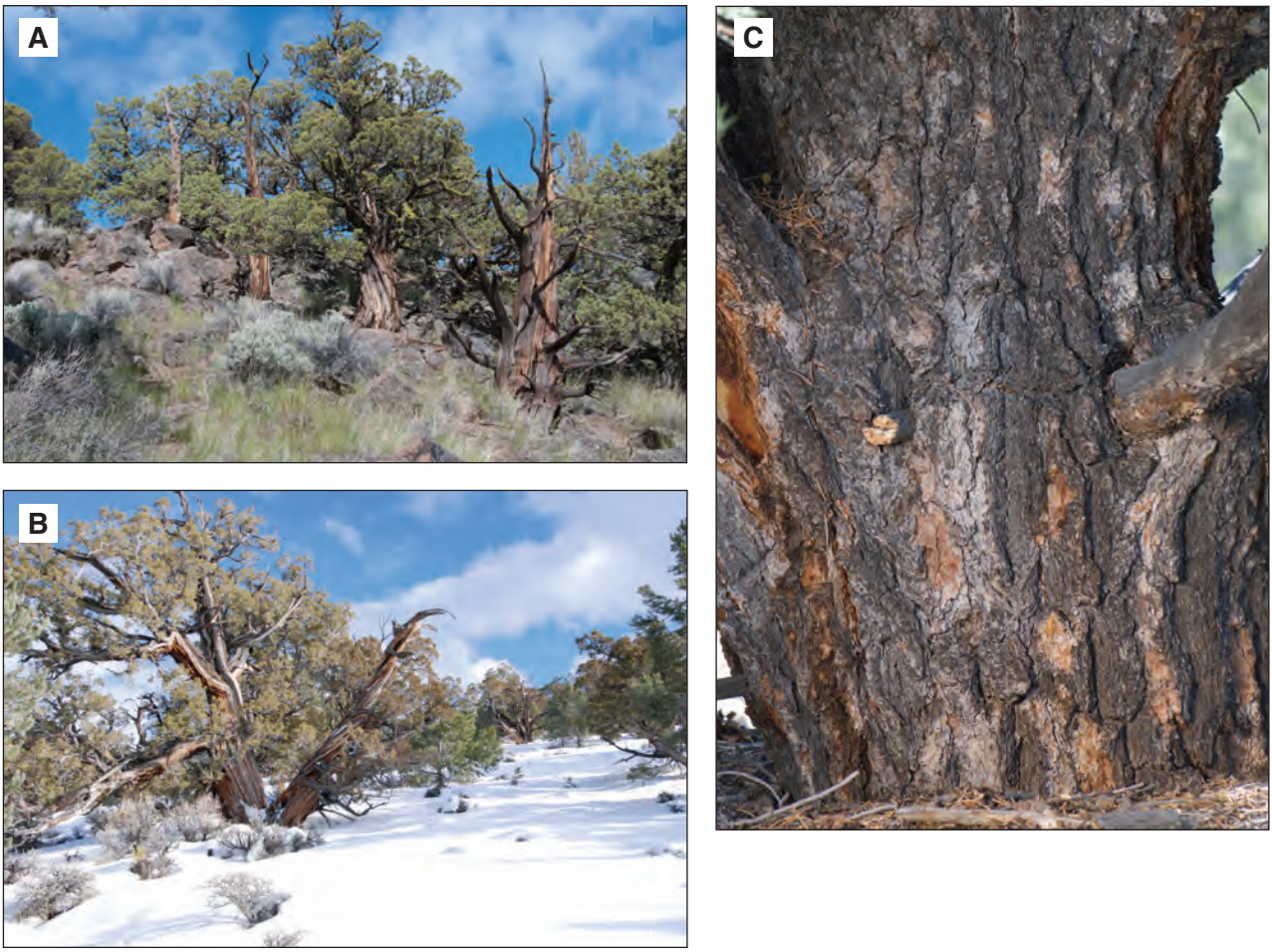

Figure 2-39—Pinyon and juniper trees begin developing old-growth characteristics as they approach 200 years of age, features that become more prominent as the tree becomes multiple centuries old. Characteristics include tree canopy shape, distinct bark characteristics, rot pockets, cavities, and branch structures—which may include large basal branches and dead or partially dead branches often covered with lichen. The stringy and deeply furrowed bark on the (A) western juniper and (B) Utah juniper are typical of trees over 300 years old. (C) The well-developed bark characteristics on this singleleaf pinyon is typical of trees over 200 years old becoming more developed with age. Note the standing dead tree in (A) has been dead for several centuries. Horse Ridge, Oregon and Schell Creek Mountains, Nevada. (Photos by Rick Miller, Oregon State University.)

Figure 2-40—The oldest trees are most commonly found on poor soils, where growth is slow and there are little to no surface fuels to carry fire. Some trees on these sites can exceed 1,000 years of age. Central Nevada. (Photo by Rick Miller, Oregon State University.)

Figure 2-41—The oldest known western juniper, near 1,650 years, occupies a protected micro-site surrounded by rocks and limited surface fuels. Horse Ridge, central Oregon. (Photo by Rick Miller, Oregon State University.)

Figure 2-42—Old-growth woodlands typically have more than 20 percent tree canopy cover with limited to substantial perennial herbaceous understory and limited to no shrub layer. The abundance of the perennial herbaceous layer is largely attributed to soil characteristics, especially soil depth, disturbance regimes, and tree density. Soils in this Phase III old-growth woodland are skeletal (more than 30 percent rock) moderately deep to deep sandy loams. Horse Ridge, central Oregon. (Photo by Rick Miller, Oregon State University.)

Figure 2-43—Scattered old-growth trees also grow in low sagebrush communities with shallow to very shallow soils but fractured bedrock. Tree canopies are usually less than 10 percent, and surface fuels are limited resulting in infrequent low intensity fires. Modoc Plateau, northern California. (Photo by Rick Miller, Oregon State University.)

Figure 2-44—Pinyon-juniper savannas most commonly occur in the Colorado Plateau. They typically have less than 10 percent canopy cover with a predominant perennial grass understory. Increases in low palatability shrubs—such as snakeweed—are indicators of drought and overgrazing. Grand Staircase, southern Utah. (Photo by Rick Miller, Oregon State University.)

Diversity and Richness

Floristic richness of pinyon and juniper woodlands has been reported to range from moderate (Christie 2009) to relatively low (Tueller et al. 1979; West et al. 1978b). Across 66 mountain ranges in the Great Basin, a total of 240 perennial and 127 annual species were recorded within the woodlands (West et al. 1978b). The researchers concluded this to be relatively low, considering the large area that was measured (463 woodland plots). At smaller scales (ranging from individual stands to watersheds), the variation in floristic diversity and richness can be very high, varying with topography, soils, disturbance regimes, and tree dominance (figs. 2-45, 2-46). Potential floristic diversity across woodlands in Arizona, New Mexico, and eastern Oregon was closely linked to the amount of available soil moisture, number of different soil types, and variation in solar radiation across the woodland or area measured (Harner and Harper 1976; Miller et al. 2000). There is also an inverse relationship between floristic richness and diversity with increasing tree dominance (Bates et al. 2000; Everett and Koniak 1981; Miller et al. 2000; Tausch et al. 1981). Plant diversity was 1.6 times greater on recently cut postsettlement woodlands compared to adjacent Phase III uncut woodlands (Bates et al. 2000). Seedbank diversity may (Koniak and Everett 1982) or may not (Allen and Nowak 2008) change with increasing tree dominance.

Competition

There is substantial evidence that there is a negative relationship between tree canopies and understory vegetation (figs. 2-28, 2-36, 2-37; Bates et al. 2000; Everett and Sharrow 1985a; Miller et al. 2000, 2014a; Roundy et al. 2014a). As trees increase in dominance, acquisition of soil resources increases and the microenvironment beneath the tree canopy changes.

Soil Water Competition

As pinyon and juniper increase on a site, a larger proportion of available soil water is used by the trees, resulting in significant declines in understory vegetation and length of the growing season. Rapid use of soil water by the trees occurs primarily during the growing season (Angell and Miller 1994; Bates et al. 2000; Emerson 1932; Miller and Shultz 1987; Roundy et al. 2014b). However, if soils are not frozen during the winter, western juniper was reported to draw down winter soil moisture, resulting in drier soils at the beginning of spring compared to adjacent sites with no trees (Jeppesen 1978). In areas where trees have been removed, the growing season of posttreatment herbaceous vegetation was increased by 3 to 6 weeks (fig. 2-47; Bates et al. 2000; Roundy et al. 2014b). During the spring, Utah and western junipers rapidly used soil water in the upper soil zone (less than 3 feet) where soil nutrient concentrations are highest and most important for the majority of herbaceous species (Angell and Miller 1994; Bates et al. 2000; Evans and Ehleringer 1994; Flanagan et al. 1992; Leffler et al. 2002; Ryel et al. 2010).

As upper soil layers become dry, trees will use deep water resources. On a site in southeast Oregon where the majority of western juniper had been removed, predawn water potentials in scattered sapling trees remained above -1.5 MPa (standard wilting point is less than -1.5) in the summer when upper soil layers were dry, indicating acquisition of available water from deeper water resources (fig. 2-47; Bates et al. 2000). Utah juniper was found to always extract water deeper in the soil profile than big sagebrush (Leffler and Caldwell 2005). Utah juniper was also able to take advantage of relatively small summer rainfall pulses of 0.39 inches (10 mm) that moistened dry surface soils (Evans and Ehleringer 1994; Flanagan et al. 1992; Leffler et al. 2002; Ryel et al. 2010). In comparison, twoneedle pinyon required greater amounts of rainfall (25 mm, 0.98 inches) to increase physiological activity (West et al. 2007a,b).

Figure 2-45—The literature reports a large variation in floristic diversity and richness in pinyon and juniper woodlands, ranging from low to moderate. The level of diversity and richness varies with topography, soils, disturbance regimes, and tree dominance. Floristic diversity and richness in this early Phase II woodland, encroaching into a mountain big sagebrush community with 14 to 16 inches of precipitation and moderately deep soils, is relatively high, but will decline with increasing tree dominance. Schell Creek Range, eastern Nevada. (Photo by Rick Miller, Oregon State University.)

Figure 2-46—Species diversity is very low in this closed pinyon and juniper woodland on shallow to moderately deep soils. There is also little recruitment of trees, and saplings have very limited leader growth, resulting from high intraspecific competition. Colorado Plateau, southern Utah. (Photo by Rick Miller, Oregon State University.)

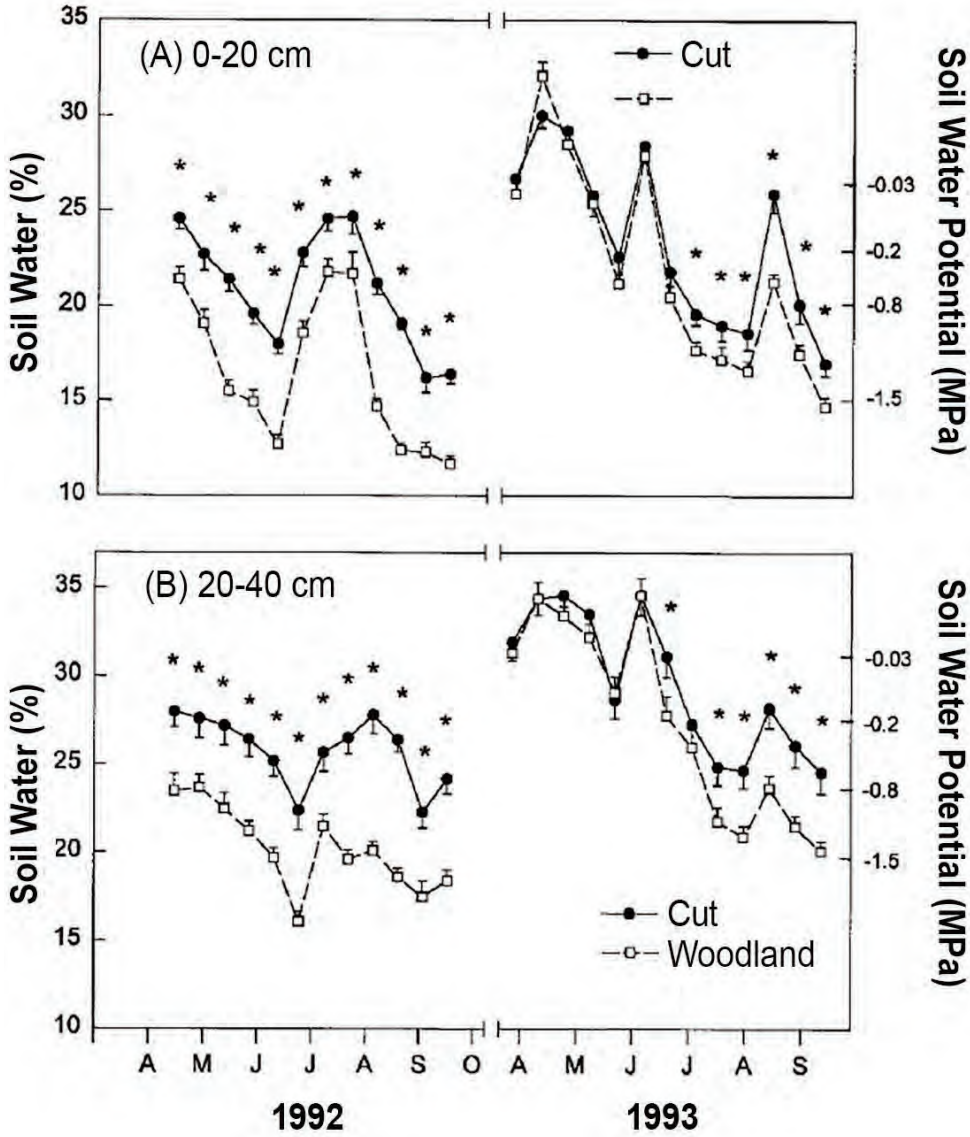

Figure 2-47—Gravimetric soil water content (percent soil water by weight) and soil water potential (less than -1.5 MPa = wilting point) in interspace soils from: (A) 0–20 cm and (B) 20–40 cm soil depth in cut and uncut Phase III woodlands. Soil water potentials were determined by predawn leaf water potential of sapling juniper trees left in the cut and uncut stands. Asterisks (*) indicate significance differences on that sampling date ($P < 0.05$) (Bates et al. 2000).

Precipitation Interception

Effective soil moisture is also reduced by pinyon and juniper through precipitation interception within the tree canopies where it is evaporated back to the atmosphere (Eddleman 1984; Skau 1964; West et al. 2007a; Young et al. 1984). Tree canopies also capture snow that is lost to the atmosphere through sublimation (Larsen 1993). The amount of moisture lost through canopy interception varies with the amount of tree canopy cover and proportion of the canopy made up of pine versus juniper, and the duration, intensity, and type of precipitation. Skau (1964) did some of the first work on the amount of rainfall interception by juniper, reporting precipitation interception by Utah juniper ranged from 7–25 percent, which varied with tree canopy density. Interception by several juniper species in the Intermountain Region ranged from 50–60 percent for low intensity and 5–35 percent

for high intensity storms (Pierson and Williams 2016). In western juniper, up to 74 percent of the precipitation was intercepted in the tree canopy area, and stem flow was absent or very limited (Eddleman 1984; Larsen 1993; Young et al. 1984). This is similar to results in a twoneedle pinyon and oneseed juniper woodland in northwestern New Mexico where snow water equivalent was 80 percent greater in openings between tree canopies compared to directly beneath the tree canopies (Breshears et al. 1997b). In addition to interception by the tree canopy, the litter-duff layer beneath the tree canopy can reduce infiltration, further reducing effective precipitation (Owens et al. 2006). For additional information see subsection "Interception" in Section 4, Ecohydrology.

Allelopathic Competition

Limited literature suggests juniper litter can reduce plant growth directly beneath the tree canopy through the release of allelopathic compounds (Jameson 1961, 1966). However, the possible production of chemical inhibitors by juniper species and what we observe in the field (fig. 2-48a,b) makes this issue unclear. In the Great Basin perennial bunchgrasses, especially Idaho fescue and bluebunch wheatgrass, often are well established beneath the tree canopy. However, seedling emergence was reported to be reduced with increasing juniper litter depth, and emergence was slower in juniper litter compared to sites with no litter (Horman and Anderson 2003). But, there was no difference 2 weeks postemergence in plant growth between plants growing in juniper litter and no litter. Beneath recently cut and downed western juniper canopies, herbaceous plants quickly establish in litter zones following tree cutting (Bates et al. 1998). In addition, seedlings and established plants grew larger than species in the adjacent interspaces, particularly annual grasses and forbs. The degree of impact of juniper litter on understory vegetation may also depend on the species growing in the duff zone (Gehring and Bragg 1992; Vaitkus and Eddleman 1987) and on litter density and depth, which can act as a physical barrier.

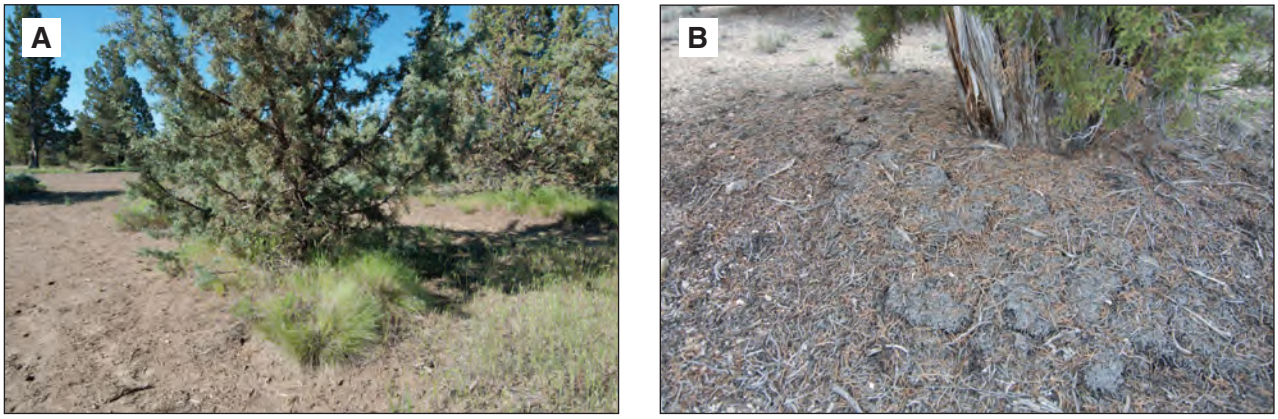

Figure 2-48—Do juniper species produce chemical inhibitors affecting understory growth? Discrepancies between current knowledge and what we observe in the field make the issue unclear. (A) Directly beneath the tree canopies, Idaho fescue can be found growing on the north side of the tree, while bluebunch wheatgrass is typically found on the south side—but in this case, cheatgrass grows on the south side of the tree. The lack of perennial grasses in the interspace indicate both poor past management and competition from the tree roots, which occupy the interspace. (B) Closed Phase III woodland with thick mats of duff beneath the tree canopy. Lack of herbaceous growth beneath may be due to chemical inhibitors, competition, or the physical barrier of the matted duff layer. (A) Central Oregon and (B) Great Basin National Park, Nevada. (Photos by Rick Miller, Oregon State University.)

Soil Nutrients

Carbon and Nitrogen

A number of factors influence the size of organic carbon (C) and nitrogen (N) pools—such as composition and structure of vegetation, depth to bedrock, coarse fragment content [particles between 0.08–9.8 inches (2–250 mm)], particle size distribution, soil bulk density, disturbance regimes, and climate (Jobbagy and Jackson 2000; Strand et al. 2008). The shift from sagebrush-grassland to pinyon and juniper woodland results in significant changes in the amounts and distribution of above- and belowground organic C and N pools (Rau et al. 2011a, 2011b, 2012). In treeless big sagebrush communities, total aboveground organic C and N averages 2 tons/acre (4.5 Mg/ha) and 0.13 tons/acre (0.3 Mg/ha), respectively (Rau et al. 2012). This is less than 10 percent of total estimated ecosystem C and N and a soil depth of 20.9 inches (530 mm) (figs. 2-49, 2-50). As pinyon and juniper increase to near closed-canopy conditions, aboveground biomass can account for 27.5 tons/acre (62 Mg/ha C) and 0.27 tons/acre (0.6 Mg/ha

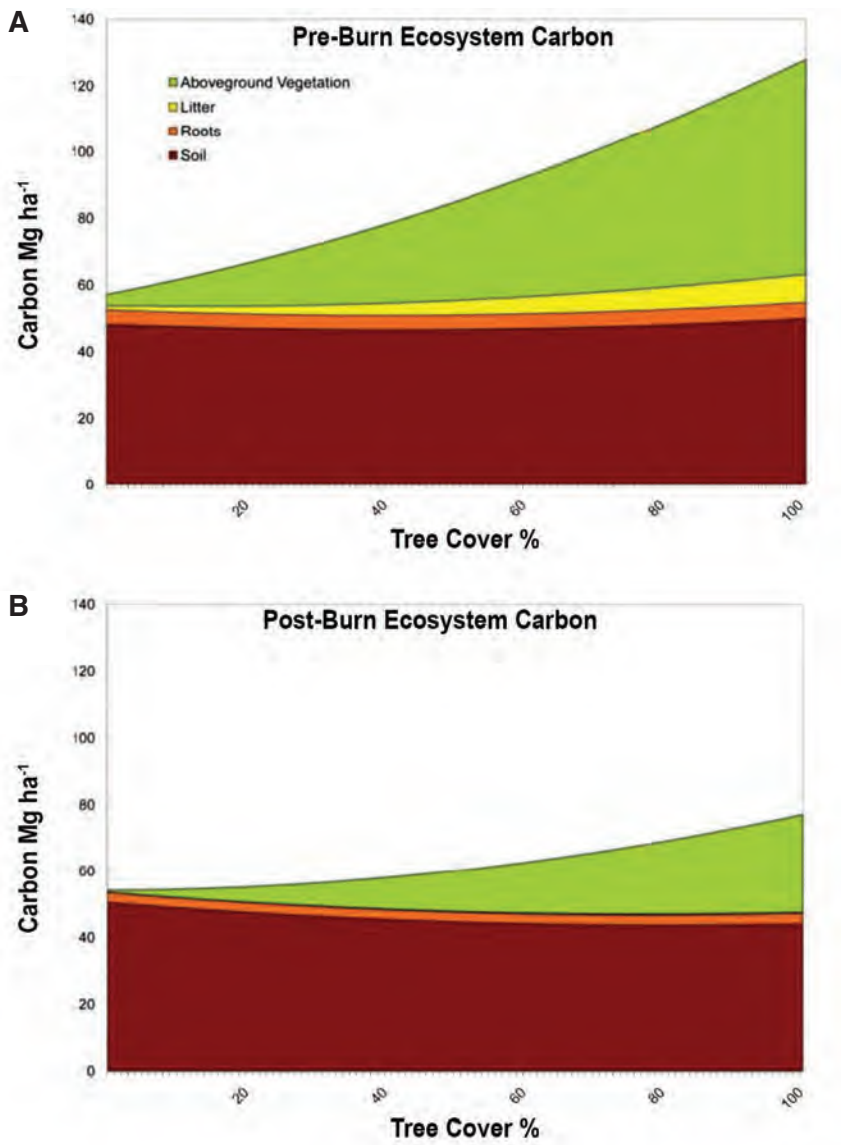

Figure 2-49—Changes in the carbon pool (A) before and (B) immediately after a moderate severity fire. Mass C Mg ha^{-1} is stacked, adding values for each ecosystem component starting at zero and ending at cumulative C mass for the ecosystem (Rau et al. 2012).

N), which is nearly 53 percent of total estimated ecosystem C and 13 percent of total estimated ecosystem N to a soil depth of 20.9 inches (530 mm). In addition to changes in aboveground pools, the increase in pinyon and juniper tree cover from early to late woodland succession resulted in an increase of 1.7 tons/acre (3.8 Mg/ha) of root organic C and 0.027 tons/acre (0.06 Mg/ha) of root N in the 0 to 35.4 inches (0 to 900 mm) of the soil profile. However, there is little change in total soil organic C and N pools, which includes coarse soil fragments.

Pinyon and juniper can also influence C and N cycling on the surface. Plant tissue can have C:N ratios of 30:1 or greater (Laungani and Knops 2009; Rau et al. 2011a). After microbial decomposition of soil organic C, C:N ratios are typically around 12:1. The higher ratios of C:N in pinyon and juniper litter compared to litter from shrubs and grasses in addition to dry climate can result in slow organic matter decomposition rates. Residence time of nondecomposed organic C beneath pinyon and juniper canopies can

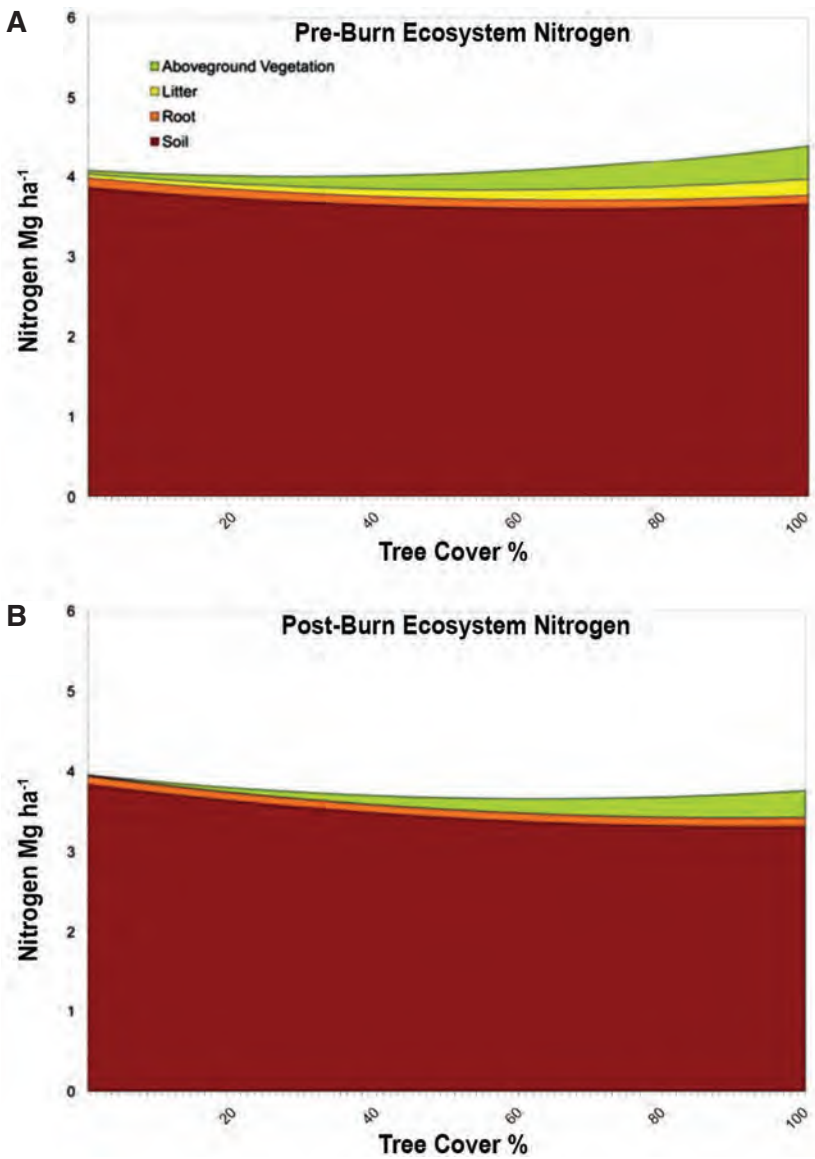

Figure 2-50—Changes in the nitrogen pool (A) before and (B) immediately after a moderate severity fire. Mass N Mg ha-1 is stacked, adding values for each ecosystem component starting at zero and ending at cumulative N mass for the ecosystem (Rau et al. 2012).

potentially be several centuries (Neff et al. 2009).

Although some consider the increased aboveground storage of C and N in pinyon and juniper woodlands a potential benefit, high-severity fires can result in large losses in both above- and belowground pools (Breshears et al. 2005; Breshears and Allen 2002; Rau et al. 2011b, 2012). The amount of biomass and total aboveground C combusted in pinyon and juniper woodlands is closely related to fire severity and plant composition. Low-intensity prescribed burns in sagebrush removed 83 percent of the aboveground biomass compared to 55 percent in denser woodlands (90 percent of the 1-hour fuels, with the majority of 10-, 100-, and 1,000-hour fuels remaining). However, since biomass in closed woodlands can be tenfold greater than sagebrush-grassland, significantly greater amounts of total aboveground organic C and N are lost. In high-severity wildfire events, combustion of trees released 70 percent of the organic C stored in aboveground biomass (fig. 2-51; Rau et al. 2010). It is likely that the majority of remaining aboveground dead biomass after such events, including tree roots, will decompose and result in the release of CO_2 directly into the atmosphere (Johnson and Curtis 2001). But charcoal and ash that remain are relatively resistant to decomposition and can persist many centuries in arid environments (Mensing et al. 1999).

Extensive tree mortality from droughts can also have large impacts on aboveground C and N, with losses similar to wildfires (Breshears et al. 2005; Breshears and Allen 2002). Although not widely documented in the Great Basin, significant drought mortality has occurred in the Colorado Plateau. An additional concern is the transition of woodlands, shrubland, and/or perennial grassland to exotic annual dominated communities, which could result in significant declines in C below 24 inches (600 mm) in soil depth (Rau et al. 2011a).

Canopy and Intercanopy Spatial Heterogeneity

There is significant spatial heterogeneity in organic C, N, and other nutrients at and near

Figure 2-51—In high severity wildfire events, combustion can release 70 percent of the organic C stored in aboveground biomass and considerable amounts of aboveground N. Stinkingwater Mountains, eastern Oregon. (Photo by Rick Miller, Oregon State University.)

the soil surface in persistent pinyon and juniper woodlands and more recent postsettlement woodlands. Litter and nutrient accumulation areas beneath the tree canopies can have three- to five times more organic C and N than the tree interspace (Klopatek 1987a,b; Neff et al. 2009). These large differences primarily occur at the surface and in the upper 3.9 inches (100 mm) of soil, with little or no differences at deeper soil depths (Neff et al. 2009; Reiley et al. 2010). Others have also reported tree canopy duff areas as accumulation areas of litter, organic C, and nutrients compared to the interspace (Bates et al. 2007a,b; Doescher et al. 1987; Everett et al. 1986a; Thran and Everett 1987).

Lower bulk density and higher pH, water holding capacity, and sand content also can occur beneath the tree canopy compared to the tree interspace (Klopatek 1987b). Benefits of these accumulation areas include relatively stable nutrient pools with very slow decomposition rates and protection of soil surface directly beneath the tree canopies from runoff and erosion. Residence time of organic C beneath tree canopies can be centuries (Neff et al. 2009). However, a drawback is that these pools are much more susceptible to loss from wildfires as compared to C stored below the top couple of inches of soil. Five to 8 years following tree removal, nutrient concentrations were still higher in the tree duff areas compared to tree interspace (Thran and Everett 1987). However, cutting and leaving trees on the ground increased decomposition rates, which were 37 percent greater than adjacent uncut woodlands (Bates et al. 2007b).

The benefits of these duff accumulation areas depend largely on how the interspace is being affected (Reiley et al. 2010). Mining of nutrients from the interspace to tree canopy duff areas has been reported by several researchers (Doescher et al. 1987; Klopatek 1987b; Tiedemann 1987). These accumulation areas may also be immobilizing nutrients for plant use. Nutrient cycling and uptake by understory vegetation may be more rapid in the tree interspace. In northcentral Arizona there were greater numbers of nitrifying bacteria in the interspaces than beneath the tree canopies, even though there was fourfold more total N beneath the tree canopies—suggesting greater N utilization in the interspace (Klopatek and Klopatek 1987). This difference could be due to slower decay rates caused by higher lignin content in tree foliage as compared to grass and shrub foliage in combination with generally drier conditions under the trees due to greater interception of rain and snow by the tree foliage as discussed in sections prior to this. However, energy of surface runoff can be increased by concentrating flows through the interspace, resulting in increased erosion resulting in the loss of N (Pierson et al. 2007). The potential negative effects of tree canopy accumulation areas depend largely on the structure and composition of interspace vegetation, which is influenced by soils (especially depth to a restrictive layer), disturbance history, and relative dominance of the tree canopy (fig. 2-52; Miller et al. 2000, 2005).

Climate Change and Effects on Pinyon and Juniper Persistence and Migration

Climates have been continually changing long before the formation of the first pinyon and juniper woodlands and have had significant impact on woodland distribution, migration, expansion, contraction, infill, composition, and structure. But recent concerns over natural climatic variation linked to anthropogenic effects on climate have raised considerable apprehension related to future impacts on agriculture, water, global economies, and wildland ecosystems including semiarid woodlands. Continued warming in the western United States is projected to have significant effects on pinyon and juniper woodlands and on factors related to all semiarid vegetation in the West, including wildfire, invasive plants, insect and disease outbreaks, snowpacks, and soil water availability.

Figure 2-52—Moderately deep to deep skeletal soils in this open Phase II old-growth woodland support perennial grass cover of 20–30 percent and 3–5 percent forb cover. Few sagebrush remain and there is limited recruitment of trees. Horse Ridge, central Oregon. (Photo by Rick Miller, Oregon State University.)

Projected Climate Change Across the Great Basin and Colorado Plateau

Global climate change models project future changes in temperature and precipitation based on concentrations of carbon dioxide (CO_2), and other greenhouse gases and information about the earth's surfaces and oceans. Climate change analyses use emissions models from the Coupled Model Intercomparison Project (CMIP) from either Phase 3 (CMIP3) or Phase 5 (CMIP5). The CMIP3 models, also known as the SRES models, assume a series of storylines concerning population growth, socio-economic development, and technological change with the A2 scenario representing business as usual (IPCC 2000). The CMIP5 models use representative concentration pathways (RCPs) based on the additional energy provided to the earth's system by greenhouse gas emissions, with RCP 8.5 representing high emissions rates and roughly equivalent to the A2 scenario (Taylor et al. 2012).

Predicting how potential change will impact pinyon and juniper depends on the degree of climate change and how climate, soils, and different plant species interact. While there is widespread scientific agreement concerning continued warming, uncertainty remains over how much additional warming will occur and how precipitation regimes will change (IPCC 2013; Melillo et al. 2014; USGCRP 2017). Changes in (1) snowpack and precipitation seasonality, amount, variability, and extremes, and (2) the frequency, duration, and severity of drought are important drivers of the potential niches for the different juniper and pinyon species. Changes in climate also drive disturbance regimes, such as insect and disease outbreaks, fire, and the extent and type of invasive plant species.

Average annual temperatures in the Great Basin and Colorado Plateau have increased, primarily in winter, with minimum temperatures increasing more than maximum temperatures (Abatzoglou and Kolden 2013; Kunkel et al. 2013a,b; USGCRP 2017). The daily difference between minimum and maximum temperatures have decreased in

fall, winter, and summer but have increased in spring (Rhines et al. 2017). The number of very warm days has increased in summer, decreased in winter, and has no clear trend in spring and fall (Yu et al. 2018). Warmer winters have led to more rain, reduced snowpack, earlier snowmelt, and earlier peak flows—with the largest changes in Oregon and northern Nevada (Fyfe et al. 2017; Gergel et al. 2017; Harpold and Brooks 2018; Harpold and Molotch 2015; Knowles 2015; Mote et al. 2018; Nayak et al. 2010). The number of days with snow cover has declined, particularly in November and March, largely due to increasing temperatures in these shoulder months (Klos et al. 2014; Knowles 2015).

Average annual precipitation has decreased in much of the western United States (Prein et al. 2016; Prein et al. 2017b; USGCRP 2017). Spring precipitation has increased slightly in the northern Great Basin (Abatzoglou et al. 2014; Kunkel et al. 2013b) while fall precipitation has increased in the central and southern Great Basin and Colorado Plateau (Kunkel et al. 2013a; USGCRP 2017). Some analyses show no statistically significant trend in annual or seasonal precipitation when analyzed over smaller geographic areas rather than multiple Major Land Resource Areas or multiple states (Abatzoglou et al. 2014; Kunkel et al. 2013a,b).

The western United States will continue to become drier overall, as projected increases in evapotranspiration outpace any increases in precipitation (Cook et al. 2004; Dai 2013; Peterson et al. 2013; USGCRP 2017). Climate scientists are uncertain how much drying will occur, largely due to difficulties in modeling summer precipitation (USGCRP 2017). Nonetheless, significant drying in spring and fall is expected by the end of the century if the current rate of greenhouse gas emissions continues.

Since 1901, the consecutive number of frost-free days has increased by 17 days, lengthening the growing season by 1–2 weeks in the western United States, but that has not resulted in an increase in plant productivity due to plant-specific temperature thresholds, plant-pollinator dependencies, and seasonal limits on water and nutrient availability (USGCRP 2017). Grasses green up earlier, but also senesce earlier as soil moisture is depleted earlier.

By mid-century, the growing season is expected to increase by 30–40 days in the northern Great Basin and by 20–40 days in the central and southern Great Basin and Colorado Plateau as compared to the 1976–2005 period (USGCRP 2017). However, growing season water balance deficits are expected to increase by mid-century and beyond except in areas with significant monsoonal precipitation (USGCRP 2017).

Temperature

Observed warming trends are expected to continue into the future (Abatzoglou and Barbero 2014; Dalton et al. 2013; Kunkel et al. 2013a,b; Melillo et al. 2014; USGCRP 2017), with the magnitude of any given change dependent on the climate model(s) and emissions or radiative forcing scenario used. At the current rate of emissions, climate models project average annual temperature to increase by 3–5 degrees Fahrenheit by mid-century and 5–9 degrees Fahrenheit by the end of the century (Garfin et al. 2014; Kunkel et al. 2013a,b; Mote et al. 2014; USGCRP 2017). Extreme temperatures would increase more than average temperatures, with the frequency and intensity of heatwaves increasing, and the frequency and intensity of cold snaps decreasing (Kunkel et al. 2013a,b; Melillo et al. 2014; USGCRP 2017). Winter temperatures are expected to increase more in the northern Great Basin than in the central and southern Great Basin and Colorado Plateau (Kunkel et al. 2013a,b; USGCRP 2017). Conversely, summer temperatures

are expected to increase more in the central and southern Great Basin than in the northern Great Basin (Kunkel et al. 2013a,b; USGCRP 2017). The number of days below freezing will decrease, while the freeze-free period and the number of days above 90 °F will increase (Melillo et al. 2014; USGCRP 2017).

Precipitation

Projected changes in precipitation are more uncertain than changes in temperature (IPCC 2013; Melillo et al. 2014; USGCRP 2017), although modeling of winter precipitation has improved in the western United States (USGCRP 2017). Changes in summer precipitation remain more uncertain due to the inability of climate models to represent the mesoscale convective storms that predominate in summer (USGCRP 2017).

At the current rate of greenhouse gas emissions, winter precipitation in the western United States is expected to increase 10–20 percent relative to the 1976-2005 average by the end of the century, while changes in spring, summer, and fall precipitation are expected to be minor relative to natural variability (USGCRP 2017). But many projections of precipitation show both a wide range of increases and decreases from current averages, thus including no change in precipitation amount (Abatzoglou et al. 2014; Dalton et al. 2013; Kunkel et al. 2013a,b), indicating high uncertainty. Pendergrass et al. (2017) project that precipitation variability will increase on all time scales (although less so in summer). The number of mesoscale scale convective storms will likely increase (Prein et al. 2017a), with individual storm cells both smaller and bringing heavier rainfall (Wasko et al. 2016).

Huang and Ullrich (2017) project an increase in the number of rainy days and the frequency of nonextreme precipitation through mid-century—but little change after that. The central and southern Great Basin and Colorado Plateau would experience an increase in warm season precipitation, and the northern Great Basin a decrease (Huang and Ullrich 2017). However, the North American monsoon is also expected to weaken significantly as the climate warms (Pascale et al. 2017), so the source of the warm season moisture for the central and southern Great Basin and Colorado Plateau is unclear. A potential source may be an increase in hurricanes and tropical storms from the Pacific that track into the southern Great Basin, bringing slow-moving, intense, and long-lasting thunderstorms (Kunkel et al. 2013a).

Precipitation extremes are expected to increase in frequency and intensity as warmer temperatures increase the water holding capacity of the atmosphere. Model results project greater change in the northern Great Basin than in the central and southern Great Basin and Colorado Plateau due to an increased incidence of long, narrow regions in atmospheric moisture flow during the cool season—narrow atmospheric rivers that transport much of the moisture from the tropics to the West (Dannenberg and Wise 2017; Prein et al. 2016; USGCRP 2017). The number of dry days and days with very light precipitation are projected to increase slightly, but the number of days with very heavy precipitation is projected to increase by more than 25 percent. The length of consecutive dry day periods may increase, although estimates on the magnitude of that change varies widely (Roque-Malo and Kumar 2017).

Snowpack

Snowpack provides a significant source of soil moisture throughout the range of pinyon and juniper woodlands (Gergel et al. 2017; Harpold and Molotch 2015), with peak annual soil moisture typically occurring during snowmelt (Harpold and Molotch 2015). Much of the Great Basin has an average winter temperature near freezing, making this area very sensitive to small changes in winter temperature (Lute and Abatzoglou 2014; Mote et al. 2005; Mote et al. 2018; Nayak et al. 2010; Safeeq et al. 2016; Tennant et al. 2017). By mid-century, at the current rate of greenhouse gas emissions, the area

expected to remain snow-dominated in winter would decrease by 3–42 percent and the area expected to become rain-dominated would increase by 23–65 percent, depending on location (Klos et al. 2014). The shift to rain-dominant winter precipitation will occur quickly in areas with gentle terrain and lower elevations across much of the northern Great Basin (Klos et al. 2014; Lute and Abatzoglou 2014). The result will be the decline in cover and amount of spring snow (Thackeray et al. 2016), although interannual variability in snow will remain an important driver of snowpack until mid-century, after which temperature will become the main driver (Safeeq et al. 2016; Thackeray et al. 2016). Snowpack is expected to all but disappear in nearly the entire pinyon-juniper zone by the end of the century (Safeeq et al. 2016).

Climate Change and Drought

There are many terms for drought—keeping the differences in mind are important for determining how drought may influence pinyon and juniper woodland extent, structure, and dynamics. Of most relevance to pinyon and juniper woodlands are (1) agricultural drought—soil moisture deficit insufficient for plant growth, (2) flash drought—relatively short periods of rapidly developing moisture deficit (Mo and Lettenmaier 2015, 2016), and (3) snow drought—snowpack deficit (Harpold et al. 2017). Ecological drought refers to the impacts on the environment and human economies from drought (Crausbay et al. 2017).

Multi-year and multi-decadal droughts are natural occurrences in the central and southern Great Basin and Colorado Plateau (USGCRP 2017). Severe droughts in the 12th, 13th and 16th centuries were of much greater spatial extent and longer duration, often lasting several decades, than any seen in the 20th century and thus far in the 21st (Peterson et al. 2013). Over the instrument record period, the interior West typically has experienced transient droughts characterized by short-term changes in duration, intensity—how hot and dry, and for how long—and severity, or overall impact (Ge et al. 2016). Drought duration and severity appear to be decreasing in the central and southern Great Basin and Colorado Plateau for intermediate and longer drought return intervals, but drought intensity is increasing for the Colorado Plateau for the longer return intervals, particularly in northern Arizona (Ge et al. 2016). Drought duration, intensity, and severity are increasing for 10-year interval time periods in the northern Great Basin but are more mixed for longer interval droughts (Ge et al. 2016). The evidence for flash droughts is relatively weak given high interannual variability in soil moisture, but one driven more by precipitation deficits is somewhat likely (Mo and Lettenmaier 2015, 2016). The number of months in moderate to extreme drought has been increasing in much of the Great Basin and Colorado Plateau (Peterson et al. 2013).

Some evidence indicates that droughts in the western United States are shifting from precipitation control to temperature control, but that evidence is limited by biases toward temperature in many models, and by the lack of soil moisture observations and subsurface modeling studies (USGCRP 2017). Other than how increasing temperatures are driving an overall increase in aridity, the evidence remains weak to show that climate change is currently driving an increase in agricultural drought frequency and severity outside the range of natural variability (USGCRP 2017). In simulations where temperature increase was not constrained, Jeong et al. (2014) projected a likely increase in drought, as measured by the Standardized Precipitation Evaporation Index (SPEI), over a 12-month period, along with increased drought duration and in cumulative drought and extreme drought severity across the Great Basin and Colorado Plateau. Longer-term droughts decrease deep soil moisture and groundwater levels. Evidence is much stronger that climate change is driving an increase in snow droughts due to the observed changes in snowfall and snowpack (USGCRP 2017).

Changes in flash droughts are more difficult to assess in semiarid climates. The incidence of heatwaves, an essential component of flash droughts, is increasing across the western United States with the northern Great Basin experiencing more heatwaves currently than in the recent past (Peterson et al. 2013). As indicated in the discussion of temperature, the frequency and severity of heatwaves are expected to increase in the future. That increase in heatwaves would seem to provide evidence for a potential increase in flash droughts, but it needs further study focused on the semiarid climates of the Intermountain West.

Climate Controls on Pinyon and Juniper Persistence and Migration

The climatic factors serving as top-down determinants of pinyon and juniper distribution include precipitation amount and precipitation seasonality, the frequency of freezing fogs in valley bottoms and Pacific fronts in late winter and early spring, and minimum winter temperatures (Cole et al. 2008a; Gibson 2011; Knutson and Pyke 2008; Munson et al. 2011; Nowak et al. 1994a; West et al. 1978). These factors also affect the frequency, duration, severity, and intensity of seasonal and longer droughts (Dai 2013; Ge et al. 2016; MacDonald and Tingstad 2007; Williams et al. 2010; Yu et al. 2018) with the exception of Pacific fronts and atmospheric circulation patterns, such as El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

Decade-scale wet and dry periods play an important role in structuring semiarid plant communities with larger amplitude (greater differences between maximum and minimum wet and dry events) and shorter duration swings in climate, promoting more rapid vegetation changes than lower amplitude (small differences between wet and dry events), longer duration swings. Decadal to multidecadal variability may either dampen or amplify the net effects of changing climate. Prolonged wet and dry periods tend to affect large areas of the western United States simultaneously (Gray et al. 2006). Drought, insects, and small fires may influence structure of persistent pinyon and juniper woodlands more than large fires (Gray et al. 2006; Romme et al. 2009), resulting in episodic mortality and establishment events. Factors that limit or reduce tree canopy densities reduce the possibility of large crown fires, while lack of fine surface fuels restricts the spread of surface fires (Andrews 2018; Kennard and Moore 2013; Rothermel 1991). Hotter, drier sites with low soil moisture capacity limit pinyon and juniper recruitment following a significant mortality event (Redmond et al. 2018).

Projections of Future Distribution

Several studies have attempted to project how the ranges of pinyon and juniper might change using a bioclimatic envelope approach. Bioclimatic envelope models use climate to define and predict the potential geographic range of a species (Araújo and Peterson 2012; Jeschke and Strayer 2008). Although bioclimatic envelope studies generally cannot account for other important factors that determine a species' actual range, they still produce reasonable results since climate is a primary determinant of potential ranges at the broad scale (Araújo and Peterson 2012; Jeschke and Strayer 2008).

Results vary, depending on the use of single or multiple climate models, the specific climate models, and the emissions scenario. Common findings include species contraction along the southern limits of current ranges and an upward shift in elevation (Cole et al. 2013; Friggens et al. 2012; Gibson 2011; Kerns et al. 2018; Rehfeldt et al. 2006). Studies evaluating the potential impacts of climate change on the ranges of pinyon and juniper in the Great Basin are rare, with most focus on the Colorado Plateau and Southwest. Much of the recent research has focused on twoneedle pinyon following the significant mortality event in the early 2000s.

Three studies project expansion of twoneedle pinyon's climate niche into Nevada and Idaho and some displacement of singleleaf pinyon (Friggens et al. 2012; Gibson 2011;

Natural Resources Canada 2017 January 4c). But that possibility would depend on a northward shift in the North American monsoon, leading to a significant increase in summer precipitation (Gibson 2011). Since most climate models project a decrease in summer precipitation, and some models predict a weakening of the North American monsoon (Pascale et al. 2017), movement of twoneedle pinyon into the Great Basin seems unlikely. More likely responses are a reduction in extent on the Colorado Plateau with a shift upward in elevation and an increase in the central and southern Rockies (Cole et al. 2008b; Gibson 2011; Natural Resources Canada 2017 January 4c).

The singleleaf pinyon climate niche may expand farther into southern Idaho and is expected to persist in northcentral Nevada (Friggens et al. 2012; Gibson 2011), although some analyses project an increased risk of contraction in Nevada and Utah (Friggens et al. 2012). At least one modeling effort suggests that the climate niche for singleleaf pinyon could extend across eastern Oregon and southern Idaho by mid-century at higher elevations—assuming the current rate of emissions (Natural Resources Canada 2017 January 4d). However, the historical migration rates for singleleaf pinyon appear to be slower than the current rates of change (Cole et al. 2013).

Utah juniper's climate niche could expand in southern Idaho by 2030 and migrate into the southeastern corner of Oregon by mid-century, with a general shift northward early in the 21st century and contraction to higher elevations by the end of the century (Friggens et al. 2012). It could contract from western Nevada and persist or expand in eastern Nevada, southern Idaho, and western Utah (Gibson 2011). A different study projected that Utah juniper climate niche would move up in elevation by around 325 feet, retreat from Utah, persist in central Nevada, and expand into southwestern Idaho and southeastern Oregon (Rehfeldt et al. 2006). A more extreme analysis projects that the climate niche for Utah juniper could expand across eastern Oregon and Washington and southern Idaho and farther in Nevada and Utah (Natural Resources Canada 2017 January 4b).

One study projects that western juniper's climate niche could contract significantly and become limited to the Sierra Nevada Mountains in California and possibly the Blue Mountains of Oregon and Washington (Gibson 2011). Another predicts a similar contraction, but also indicates western juniper could persist near the Cascades in central Oregon as well (Natural Resources Canada 2017 January 4a). Kerns et al. (2018) found it unclear if western juniper would expand or contract in the Blue Mountains, as some dynamic vegetation models treat novel climates as unsuitable, but the actual suitability of those climates is not known. Conversely, Creutzburg et al. (2015) projected that western juniper would continue expanding in Oregon, but at a slower rate than under the current climate. Halofsky et al. (2013) found that western juniper could expand in central Oregon, moving into areas currently occupied by ponderosa and lodgepole pine through mid-century, but then decline to near current levels by the end of the century, with expansion and contraction rates and timing varying by climate model.

In order for pinyon and juniper ranges to shift upward in elevation and northward in latitude, they must be able to disperse in appropriate directions. However, recent emphasis on reducing pinyon and juniper encroachment into sagebrush to protect and restore habitat for sagebrush obligate species, reduce fire risks, and preserve certain landscapes and plant communities may reduce the species migrations discussed above. This potential conflict in certain land management objectives and adapting to climate change has been recognized at City of Rocks National Reserve in southeastern Idaho, the current northernmost

limit of singleleaf pinyon (Powell et al. 2013). Prevention of pinyon and juniper migration to meet other land use objectives could lead to species contraction, or in more extreme cases, local extirpation.

Factors Influencing Pinyon and Juniper Persistence and Migration

Recruitment

Pinyon and juniper expansion rates are limited by seed dispersal distances and the conditions needed for establishment (Bradley 2010). Climate and climate change influence interannual variability in seed production, seed viability, and seedling establishment (see Seed and Seedling Ecology subsection) as well as tree growth and maturation rates (Enright et al. 2015; Knutson and Pyke 2008; Munson et al. 2011; Redmond and Barger 2013; Redmond et al. 2012; Redmond et al. 2017; Williams et al. 2010). In addition, higher temperatures generally accelerate the development of insects while increased atmospheric CO_2 concentrations reduce the nutritional quality of plants by changing the C:N ratio. That change leads to higher levels of herbivory so that the animal can get enough protein (Bale et al. 2002; DeLucia et al. 2012), although the impacts of climate change on seed predators remains little studied (Lewis and Gripenberg 2008). If seed predators respond the same way as defoliators and bark beetles, climate change would effectively reduce seed crops in both pinyon and juniper. Most pinyon and juniper seedlings are associated with scatter caches by rodents and birds (pinyon) or fecal deposits from birds and mammals (juniper) with most establishment under nurse plants (Chambers 2001; Chambers et al. 1999a). As such, the potential migration or persistence of pinyon and juniper depends in part on how climate change may impact their dispersers and suitable nurse plants (Mueller et al. 2005b). Changes in recruitment and maturation in combination with changes in disturbance regimes can affect the ability of a species to migrate and persist in the face of climate change (Enright et al. 2015).

Drought Effects on Persistence and Migration

A cycle of multiple wet years followed by multiple dry years typifies the Great Basin (fig. 3-12a; Miller et al. 2011; Pilliod et al. 2017). Although not explicitly studied, a similar cycle of wet and dry years likely occurs in the Colorado Plateau (fig. 3-12b). Such cycles are related to the ENSO index with more protracted droughts driven in part by sea surface temperatures consistent with ENSO as well as the PDO and Atlantic Multidecadal Oscillation (AMO) (Breshears et al. 2005; Shinneman and Baker 2009). Drought is probably the single greatest cause of pinyon and juniper mortality—in large part because it is a subregional to regional event rather than a localized event and is often linked to insect and disease infestations. In both the Great Basin and Colorado Plateau, drought can kill pinyon and juniper directly or, more commonly, facilitate the occurrence of another factor such as insect outbreak, wildfire, or the spread of invasive annual grasses.

Drought directly kills pinyon and to a lesser degree juniper through carbon starvation, hydraulic failure, or both (McDowell et al. 2008; Plaut et al. 2013; Sevanto et al. 2014) and increased vulnerability of drought-stressed trees to infestations (Gaylord et al. 2013). In the early 2000s, drought events had been characterized as a climate-change-type drought (e.g., Bowker et al. 2012; Breshears et al. 2005; Breshears et al. 2009; Clifford et al. 2011). A climate-change-type drought is a prolonged, extreme drought resulting in mass mortality of woody plants across regional or subcontinental scales and driven by warmer temperatures (Bowker et al. 2012; Breshears et al. 2009; Huang et al. 2015). This type of drought results in large-scale reorganization of woody plant distribution in a matter of years or decades, instead of centuries or millennia. For example, severe drought in northern New Mexico in the 1950s resulted in a 1.2 mile upward shift in the ecotone

between ponderosa pine and pinyon and juniper woodland that has persisted for at least 40 years, with the change occurring in less than 5 years (Allen and Breshears 1998). A multi-decade drought in the 13th century on Dutch John Mountain in Utah apparently resulted in widespread mortality of Utah juniper, which was then largely replaced by twoneedle pinyon during subsequent wet periods in the 14th century (Gray et al. 2006). The drought in the early 2000s reduced canopy cover by 55 percent in northern Arizona, exceeding the 32 percent gain in canopy cover between 1936 and drought onset (Clifford et al. 2011).

Widespread mass mortality events have been documented and studied in the Southwest and Colorado Plateau from the 1950s and early 2000s, largely involving twoneedle pinyon and oneseed juniper. Drought-related mortality events of similar magnitudes have not been documented in the Great Basin, although smaller scale drought-related die-offs have occurred in Nevada and southern California (e.g., Biondi and Bradley 2013; Greenwood and Weisberg 2008; Meddens et al. 2015). The primary difference between the 1950s drought and the 2000s drought was temperature. The drought in the early 2000s was not as dry as the 1950s drought but was considerably warmer across the range of twoneedle pinyon (Breshears et al. 2005).

Warming temperatures are expected to lead to mass mortality events across the Southwest throughout the 21st century (Adams et al. 2009; Adams et al. 2017; Clifford et al. 2011; McDowell et al. 2016). Increasing temperatures lead to increased water stress by increasing atmospheric demand for water—accelerating the rate of soil drying and increasing tree respiration (Adams et al. 2009; Macalady and Bugmann 2014; McDowell et al. 2008). Sites already subject to chronic water stress and that have experienced high mortality in past droughts are more likely to experience higher tree mortality than wetter sites (Clifford et al. 2011; Greenwood and Weisberg 2008; Mueller et al. 2005a; Peterman et al. 2013). Adams et al. (2009) found that increasing temperatures shorten the time to mortality in twoneedle pinyon from about 6 months to 4 months with an expected fivefold increase in the frequency of regional die-offs. McDowell et al. (2016) projected a greater than 50 percent decrease in conifers across the northern hemisphere by the end of the 21st century. But they also stated that the decrease could be an underestimation due to the need to oversimplify tree physiology in dynamic global vegetation models—the models also underestimated tree mortality in the early 2000s drought. Those same models projected one to three die-offs in the southern Great Basin and southern Colorado Plateau but no mortality events in the remainder of the Great Basin and Colorado Plateau (McDowell et al. 2016).

Several studies have attempted to develop climate-related predictors of drought mortality. In northern New Mexico, twoneedle pinyon die-off occurred where the 2-year cumulative precipitation was less than 24 inches (600 mm) and where warm season vapor pressure deficit exceeded 1.7 kPa (Clifford et al. 2013). Huang et al. (2015) identified a tipping point in mortality rates when the 11-month standardized precipitation evaporation index (SPEI, based on both precipitation and evapotranspiration) reached -1.64, using July as the end month. Persistence of drought over 11 months at that severity was associated with negligible or no radial growth in twoneedle pinyon pine and subsequent mortality. Breshears et al. (2009) found twoneedle pinyon died when leaf water potential stayed below the zero carbon assimilation point for at least 10 months. Adams et al. (2017) found that the time to mortality for twoneedle pinyon seedlings decreased by 5.2 percent for each 1.8 °F increase in ambient temperature. A temperature increase of 7.2 °F would result in 7.5 seedling mortality events from drought per century while a 14.4 °F increase would result in 14.7 events per century (Adams et al. 2017). Since all these studies involved only twoneedle pinyon, it is not clear if these potential predictors would apply to singleleaf pinyon, and juniper is generally more drought resistant then pinyon.

Insect and Disease Outbreaks Effects on Persistence and Migration

Insects and disease outbreaks have been closely linked to climate, particularly drought conditions, resulting in extensive woodland mortality. These interactions are discussed in the subsection "Insects, Nonvascular Plants, and Disease Associated with Pinyon and Juniper." Future projections of climate change are expected to increase stress in trees, increasing their vulnerability to various pests.

Wildfire Effects on Persistence and Migration

Several studies indicate fire regimes are changing in pinyon and juniper vegetation types, with increases in burned area, in fire size (for at least the largest fires), and in the number of fires (e.g., Balch et al. 2013; Board et al. 2018; Dennison et al. 2014; Morton et al. 2013). The fire season is getting longer in the central and southern Great Basin (based on start dates for large fires), and fire rotations are getting shorter in all pinyon and juniper vegetation types (Board et al. 2018). Some of the shortening, however, may be more due to the effects of invasive annual grasses and increases in human ignitions than to changing climate (Balch et al. 2013; Floyd et al. 2017; Romme et al. 2009). Many studies found that historical fires in persistent pinyon and juniper woodlands were typically infrequent, small, and high-severity events (Bauer and Weisberg 2009; Floyd et al. 2008; Floyd et al. 2017; Romme et al. 2009; Shinneman and Baker 2009).

Fires in pinyon and juniper savanna and at the ecotone with ponderosa pine or mixed conifer were more likely spreading, low-severity fires (Biondi et al. 2011; Cheek et al. 2012; Margolis 2014; Miller et al. 2005). Infilling of trees that increase canopy continuity, invasive annual grasses, and wet and dry cycles all appear to increase the risk or incidence and size of mixed and high-severity fire (Balch et al. 2013; Board et al. 2018; Cheek et al. 2012; Floyd et al. 2004; Floyd et al. 2017; Romme et al. 2009). Projections of how much change has actually occurred depends on the time period assessed, the geographic divisions used, whether pinyon and juniper woodlands are lumped with forests, and how a burned area was defined. Regardless, the consistency of these analyses in change (increasing) indicates that changes are not artifacts of the various methodologies and data sets used.

Understanding climate-fire connections and interactions is important to understand why fire regimes have been changing in recent years, and how they may change in the future. Climate factors influencing fire regime characteristics include cool season storm track position (Dannenberg and Wise 2017), current and antecedent drought status (Abatzoglou and Kolden 2011; Kitzberger et al. 2017; Littell et al. 2009; Morton et al. 2013), and temperature and precipitation in different seasons (Abatzoglou and Kolden 2011; Littell et al. 2009; Morton et al. 2013; Sheehan et al. 2015)—all of which vary across the Great Basin and Colorado Plateau. By influencing soil moisture availability and how rapidly or slowly it is depleted, these factors affect the arrangement of different types of live and dead fuels, the dominant vegetation, and live fuel moisture, which equates to fuel amount, continuity, and availability. Further, these factors drive seasonal drying and drought status, the top-down climate drivers of fire regimes (Abatzoglou and Kolden 2011, 2013; Kitzberger et al. 2017; Littell et al. 2009; Morton et al. 2013; Sheehan et al. 2015). Short-lived critical fire weather and the incidence of dry lightning events are important drivers for individual fires as well (Abatzoglou and Kolden 2011).

It is not clear whether pinyon and juniper woodlands function more like forests or like sagebrush and grasslands for the relative importance of antecedent conditions verses year-of-fire conditions in controlling area burned. Analyses rarely separate these woodlands from other major vegetation types. In dense pinyon and juniper woodlands with little vegetation in the understory, year-of-fire conditions may well be more important, given that stand structure is more similar to moister conifer forests (fig. 2-53).

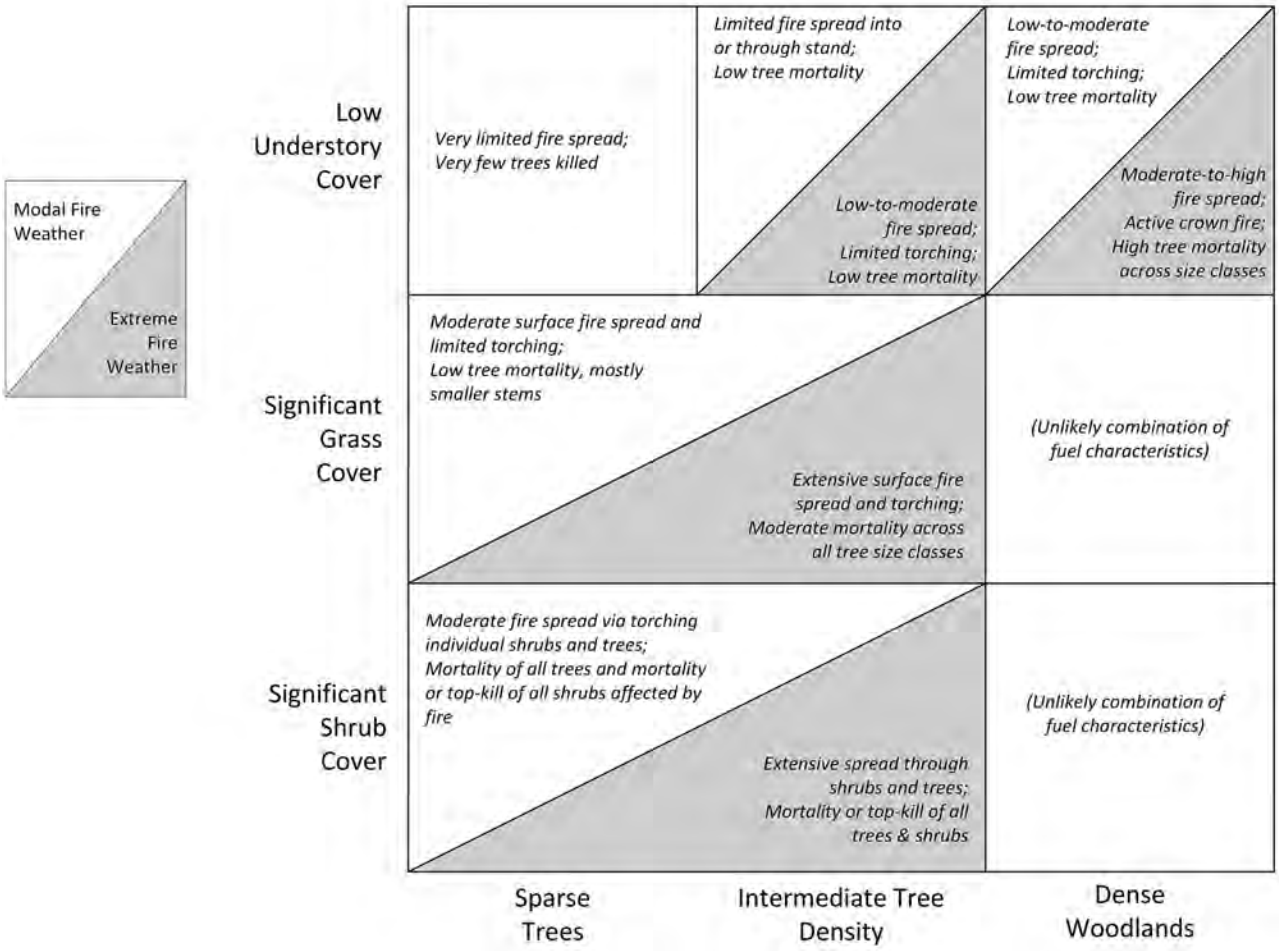

Figure 2-53—Probable fire behavior following a single ignition event in pinyon and juniper vegetation with respect to variability in tree density (horizontal axis) and understory fuel characteristics (vertical axis). Split cells reflect variable fire behavior, spread dynamics, and tree mortality under modal (80th percentile fire weather) in the unshaded upper left vs. extreme (95th percentile) fire weather conditions in the shaded lower right (from Romme et al. 2009).

In pinyon and juniper savannas with open canopies and a high proportion of grasses, or a shrub-steppe in the early stages of encroachment with high cover of shrubs and grasses, antecedent conditions may well be more important for building the necessary surface fuel loadings and continuity. In pinyon and juniper woodlands with an intermediate stand structure and understory composition between savanna and dense woodland, both antecedent and year-of-fire conditions may be important, the relative importance of each shifting as tree canopy cover increases and understory shrubs and grasses decline.

In forests, the amount of area burned is strongly correlated with temperature, precipitation, and drought in the year of the fire (Abatzoglou and Kolden 2011; Kitzberger et al. 2017; Littell et al. 2009; Westerling et al. 2006). These correlations are present but weaker in nonforest vegetation community types. Cooler temperatures and increased precipitation in the previous 1 to 3 years (usually winter and spring in the Great Basin and Colorado Plateau and summer in the Colorado Plateau) are more strongly correlated with area burned (Abatzoglou and Kolden 2011; Crimmins and Comrie 2004; Kitzberger et al. 2017; Littell et al. 2009; Margolis 2014). These conditions produce the needed surface fuel amount and continuity to support large fires in subsequent years (Littell et al. 2009; Morton et al. 2013). Morton et al. (2013) found that prolonged dry

periods of 2–6 months are still needed in grasslands and woodlands where live fuels dominate the surface fuels. Such conditions essentially convert live grasses into fine, dead fuels and are likely important in driving the live moisture content downwards in shrubs and conifers.

Climate controls on the amount of area burned change during the fire season. Even in forests, antecedent conditions are important only in the early part of the fire season (Abatzoglou and Kolden 2011; Morton et al. 2013), largely affecting season start date, as indicated by the first occurrence of a large fire, usually defined as a fire of at least 400 ha (1,000 acres). In-season conditions largely drive area burned and indicators of fire season severity in the middle and later parts of the fire season (Abatzoglou and Kolden 2011; Morton et al. 2013). In any ecosystem where live fuel moisture content is an important driver of fire season characteristics and, ultimately, fire regime characteristics, measures of moisture availability and moisture demand are better indicators of fire season potential than temperature and precipitation alone (Abatzoglou and Kolden 2011, 2013).

Potential Effects of Climate Change on Fire Regimes

Understanding how climate change may affect fire regimes in pinyon and juniper woodlands requires an understanding of how various indicators of drought occurrence, frequency, and severity may change. Measures to consider include seasonal and interannual changes in soil moisture, cloudiness, and vapor pressure deficit or evapotranspiration demand (Abatzoglou and Kolden 2011, 2013; Gergel et al. 2017; Kitzberger et al. 2017; Morton et al. 2013; Parks et al. 2016). However, predicting changes in cloudiness, which affects incoming shortwave radiation, and precipitation amount and timing have proven difficult in climate models, increasing the uncertainty in projections of future fire regimes. In addition, some expected changes differ across the Great Basin and Colorado Plateaus.

The northern Great Basin is expected to see an increase in the frequency of wet winters, with a greater fraction of annual precipitation occurring in November through March (Abatzoglou and Kolden 2011) and decreases in dead fuel moisture content (Gergel et al. 2017). The southern Great Basin and northern Colorado Plateau are projected to see little change in the frequency of wet winters and in dead fuel moisture content (Abatzoglou and Kolden 2011; Gergel et al. 2017). The southern portion of the Colorado Plateau is projected to experience an increase in the frequency of dry winters and decreases in dead fuel moisture content (Abatzoglou and Kolden 2011; Gergel et al. 2017). Across the area, a persistent northward shift in cool season storm tracks would reduce precipitation—with more area affected closer to the U.S./Canada border as the storm tracks shift (Dannenberg and Wise 2017), affecting soil moisture content in spring.

As discussed earlier, an increase in cool season rain and decrease in snow would lead to an earlier start to the growing season and earlier depletion of soil moisture, affecting live fuel moisture content during the fire season. Modeling by Parks et al. (2016) indicated soil water deficits would increase in summer, with greater deficit increases in the southern Great Basin and Colorado Plateau than the northern Great Basin. Littell et al. (2016) also found increases in soil water deficit, but the greater increases in the northern Great Basin and eastern Nevada, and decreases in much of the Colorado Plateau. In contrast, Gergel et al. (2017) projected increases in summer soil moisture in lowlands, but with considerable variability in model outputs, and decreases in higher elevations due to earlier snowmelt. Given the projected increases in temperature and associated evapotranspiration demand, it seems decreases in summer soil moisture deficit are more likely, except in areas where summer moisture remains abundant. Fire season would start earlier, with the median start date advancing by 1 to 4 weeks with an additional 1 to 3 weeks of extreme fire danger across the Great Basin and Columbia and

Colorado Plateaus (Abatzoglou and Kolden 2011). Fire return intervals are projected to decrease, and average or median annual area burned to increase (Abatzoglou and Kolden 2011; Sheehan et al. 2015). Continued aggressive fire suppression would somewhat lengthen mean fire return intervals and reduce average annual area burned as compared to the present but would likely lead to an increase in fire severity due to an increase in fuel loading and continuity (Parks et al. 2016; Sheehan et al. 2015).

Invasive Annual Grass Effects on Persistence and Migration

The ability of invasive annual grasses to establish and persist in a given area depends on several factors. First, environmental characteristics, such as the timing and amount of precipitation, soil temperatures, and other soil characteristics, determine those conditions in which a species can maintain itself in the absence of competition, facilitation, and other species interactions. This is the fundamental niche as defined by Hutchinson (1957) and it determines the broadest extents of a species' potential distribution on the landscape. Second, interactions of a species with the native plant community determine those conditions under which a species can actually persist. This is the realized niche; it is a subset of the fundamental niche and it determines the actual distribution of an invading species on the landscape (Hutchinson 1957). Finally, disturbances such as human development, inappropriate livestock grazing, wildfire, management actions, and climate change can alter both environmental conditions and species interactions and thus the fundamental and realized niches of invasive plant species.

The distributions of invasive annual grasses are related to mean annual maximum and minimum temperatures and mean annual precipitation (Brooks et al. 2016) and to the relative abundances of woody vs. perennial herbaceous species in the plant community (Bradford and Lauenroth 2006; Chambers et al. 2016a). Several studies show that cheatgrass is limited by cold soil temperatures at high elevations and low soil water availability at low elevations but is common over a wide range of intermediate elevations due to favorable conditions for its establishment, reproduction, and persistence (e.g., Chambers et al. 2007; Meyer et al. 2001). Perennial herbaceous species, especially grasses, are among the strongest competitors for invasive annual grasses, like cheatgrass (Bansal and Sheley 2016; Bradford and Lauenroth 2006; Brummer et al. 2016).

The relative abundance of woody plants or grasses is strongly influenced by differences in the overlap between the wettest part of the year and the warmest part of the year (Sala et al. 1997). The relative abundance of shrubs increases with a higher proportion winter precipitation and more deep soil water storage, while the relative abundance of perennial grasses increases with a higher proportion of spring and summer precipitation (Sala et al. 1997). Resistance to invasive annual grasses like cheatgrass increases as (1) temperatures decrease, precipitation increases, and productivity of the native community increases, (2) the proportion of precipitation that arrives in summer increases and lifeform dominance switches from shrubs to perennial grasses, and (3) the increase in number of years with insufficient precipitation for annual grass establishment and reproduction (fig. 2-53; Chambers et al. 2016b). In the Great Basin, cheatgrass cover after fire was lower on sites with wetter winters and early springs that favored perennial herbs, while cover was higher on sites with warmer and wetter falls and warmer late springs that favor its germination and growth (Roundy et al. 2018). Resistance can decrease with increased variability in precipitation, especially if rainfall is higher at times that enhance establishment and reproduction of invasive annual grasses (Abatzoglou and Kolden 2011).

Invasive annual grasses inhibit establishment and reestablishment of both pinyon and juniper by increasing the fire frequency (Nowak et al. 1994a) and preventing the reestablishment of suitable nurse shrubs (Miller et al. 2008). Climate change may favor

invasive annual grasses over native perennial grasses (Abatzoglou and Kolden 2011; Bradley et al. 2016), but this will depend on how climatic suitability for the individual species shifts, the capacity of a species to migrate to a climatically suitable area, and the interacting effects of both increasing human disturbance and changes in wildfire regimes. Pinyon and juniper expansion may also favor invasive annual grasses by reducing competitors in the understory in areas that are climatically suitable for the invasive annual grasses (Chambers et al. 2014; Miller et al. 2005; Miller et al. 2008). As the native understory declines, invasive annual grasses, such as cheatgrass, can exploit the increase in soil water and nutrient availability, especially after fire or management actions that reduce trees (Roundy et al. 2018, 2014a). Most research available on invasive species investigates how cheatgrass may respond to climate change; other invasive annual grasses remain little studied.

Less frequent but heavier spring rain events appear to favor medusahead over cheatgrass due to enhanced root growth (Bansal et al. 2014). Cheatgrass and ventenata, or North Africa grass, appear to respond more to total cumulative soil moisture than to different sizes and frequencies of water pulses (Bansal et al. 2014). Ventenata closely associates with medusahead in ephemerally wet soils with a higher clay content and lower phosphorus and potassium concentration (Jones et al. 2018) so may respond similarly to medusahead as the climate changes.

Cheatgrass exhibits high phenotypic plasticity for flowering, growth, and seed production and has the potential for rapid response to climate change (Hufft and Zelikova 2016). Warming promotes earlier growth and flowering, a longer effective growing season, and increased seed and biomass production, but only following wet winters and early springs with high soil water availability (Hufft and Zelikova 2016; Wolkovich and Cleland 2014). Warming and reduced summer precipitation is projected to favor expansion of cheatgrass into higher elevations and contraction in lower elevations; the greater the change in summer conditions, the greater the expected shift in cheatgrass (Bradley et al. 2016). Red brome is already present throughout the Great Basin and may replace cheatgrass at lower elevations (Bradley et al. 2016).

In the warmer central and southern Great Basin, increasing aridity and drought frequency will likely increase native plant stress and mortality, thereby creating opportunities for invasive annual grasses, with cheatgrass expansion at higher elevations and red brome expansion at lower elevations (Abatzoglou and Kolden 2011; Bradley et al. 2016). In the cooler northern Great Basin, warmer, wetter winters and an increased frequency of wet winters will likely favor cheatgrass germination, growth, and seed production (Abatzoglou and Kolden 2011; Balch et al. 2013; Bradley et al. 2016; Pilliod et al. 2017; Wolkovich and Cleland 2014; Zelikova et al. 2013). In contrast, if winters are drier and warmer, cheatgrass may exhibit progressively lower biomass and reproduction as temperature increases (Zelikova et al. 2013).

Across the Great Basin, climate change will likely enhance the annual grass-fire cycle (Abatzoglou and Kolden 2011). Several studies found that increased atmospheric CO_2 concentrations resulted in increased cheatgrass biomass, and thus fuels, when soil water and nutrients were not limiting to its establishment and growth (Hungate et al. 1996; Larigauderie et al. 1988; Nowak et al. 2004). Elevated CO_2 may also increase cellulose and lignin content in cheatgrass, which reduces digestibility and decomposition rates (Ziska et al. 2005) thereby increasing down and standing litter. Cheatgrass may have a more noticeable response to higher atmospheric CO_2 concentrations in the northern Great Basin if projections for wetter winters are accurate.

SECTION 3: 20,000 YEARS OF WOODLAND HISTORY

Climate is the primary driver of vegetation dynamics in both time and space—through its effects over seed crops, plant establishment, mortality, persistence, and the long-term and pervasive influence on disturbance regimes.

Summary

Presettlement

Climate is the primary driver of woodland dynamics, resulting in expansion, contraction, migration, and changes in woodland structure and species composition (Cole et al. 2013; Nowak et al. 1994a; Wigand et al. 1995). During the Glacial Maximum 20,000 years ago, precipitation was 1.3 to 1.5 times greater across the Intermountain Region, and temperatures 9.9–12.6 °F cooler in the Great Basin and 5.4–7.2 °F cooler in the Colorado Plateau than current conditions. In response to long-term periods of changing climate, pinyon and juniper woodlands moved up and down in elevation by as much as 3,000 feet and individual tree species have migrated hundreds of miles north. Transitions between cool and wet and warm and dry periods typically resulted in significant changes in woodland distribution, abundance, and structure.

Although climate is a major factor influencing pinyon and juniper woodland dynamics, it is closely linked to important woodland disturbance factors including fire, insect infestations, and disease. The transition from the cool and wet Neoglacial to the warm and dry Medieval Warm Period resulted in a large reduction of pinyon and juniper woodlands and is marked by significant increases in ash and large charcoal suggesting a large increase in fire across the Intermountain West. It is also likely that insect infestations increased during increasing drought conditions. Although climate is the primary driver of vegetation dynamics, its effects on woodland dynamics cannot be separated from other disturbance factors.

Postsettlement

The 1850s marked the end of the Little Ice Age and the early 1860s a significant rise in modern anthropogenic impacts throughout the Intermountain West. Prior to Eurasian settlement, evidence suggests pinyon and juniper woodlands were slowly expanding and infilling (Mehringer and Wigand 1990). Based on multiple tree-ring studies across the Great Basin and Colorado Plateau, rates of tree infill into woodlands and savanna, and expansion into adjacent sagebrush steppe, shrublands, grasslands, and riparian have significantly increased shortly after Eurasian settlement (Miller et al. 2008). This increase most commonly peaked in the early 1900s across both the Great Basin and Colorado Plateau, during a persistently wet period in the West between 1905 and 1917 (Barger et al. 2009; Biondi and Bradley 2013; Floyd-Hanna et al. 2004; Margolis 2014; Miller et al. 2008). The rapid increase in tree expansion and infill is attributed to climate, grazing, reduced fire occurrence where surface fuels were once adequate to support surface fires, and increased CO_2 levels, which increases water use efficiency in conifers.

Climate conditions in the late 1800s and early 1900s were ideal for cone production, tree-seedling establishment, and rapid growth rates. However, periods of increased moisture can result in the accumulations of fine fuels, resulting in the increase of widespread fires across the West. But large numbers of livestock in the late 1800s and early 1900s significantly reduced fine fuel loads and coincides with a significant decline in fires. The sudden decline in fire occurrences in the late 1800s was like no other in the last 3,000 years (Marlon et al. 2012). Several forest inventories in Nevada, Utah, and eastern California reported over 60 percent of the pinyon and juniper woodlands were

less than 150 years old (Bolsinger 1989; Menlove et al. 2013; O'Brien and Woudenberg 1999). But tree chronologies and inventories also indicate a significant portion of pinyon and juniper woodlands in the West are persistent, often showing old-growth traits. However, many of these stands have also changed in structure resulting from infill over the past 170 years.

Prehistory of Expansion, Infill, and Contraction

Dramatic changes in temperature and the abundance and seasonal distribution of precipitation have occurred across the Intermountain Region over the past 100,000 years. The most significant change in climate occurred during the transition between the Glacial Maximum (20,000 ± 2,000 years ago) in the late Pleistocene (126,000 ± 5,000 to 11,000 years ago) to the peak of the Holocene Thermal Maximum (around 6,000 years ago) (fig. 3-1; Renssen et al. 2009). The Glacial Maximum was the period when ice sheets extended across the most land surface, temperatures were coolest, and evapotranspiration at its lowest in the past 130,000 years (fig. 3-2). In contrast, the Holocene Thermal Maximum was the warmest and driest period resulting from storm tracks being deflected northward. These changes in temperature and moisture had significant effects on woodland and shrubland communities, soils, and hydrology across the Intermountain Region. Lakes and marshes expanded and contracted and elements of current shrubland and woodland communities moved up and down in elevation, in some cases forming communities with entirely new compositions of plants. Some tree species migrated hundreds of miles northward with rising temperatures during the late Pleistocene and Holocene. But, arguably, the most dramatic changes in Intermountain vegetation have occurred in the last 200 years.

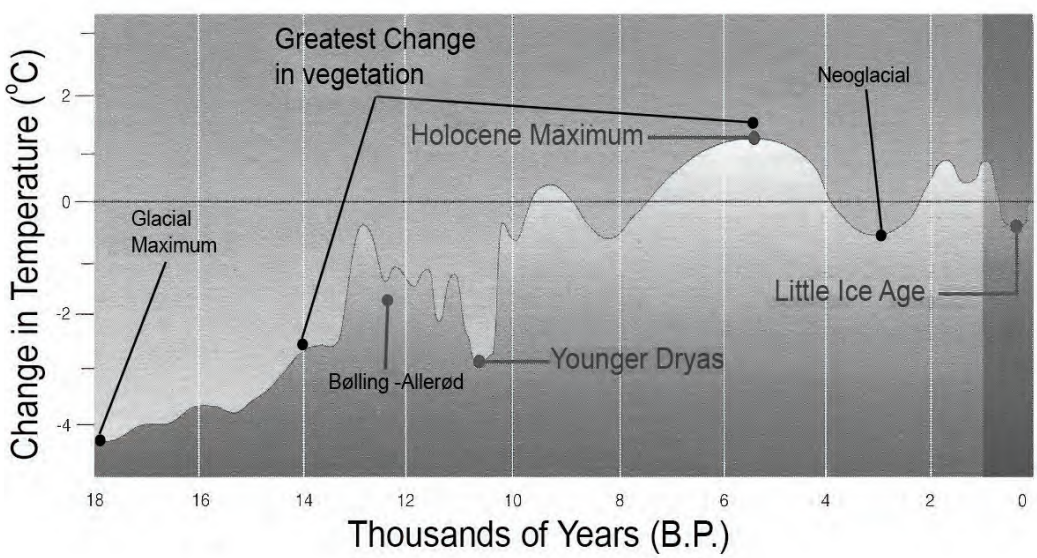

Figure 3-1—Variations in surface temperature for the past 18,000 years as estimated from a variety of sources, principally isotope ratios from Greenland ice cores. The onset and subsequent surface temperatures characteristic of the present interglacial or Holocene Epoch are highlighted. Of note are century-scale oscillations in temperature during the period of deglaciation between 15,000 and 10,000 years B.P. and a broad Holocene maximum about 5000 to 6000 years B.P. when summer temperatures may have been 1 to 2 °C (1.8 to 3.6 °F) warmer than the present era (Eddy and Bradley 1991). The estimated greatest change in vegetation occurred between 5,000–14,000 years ago.

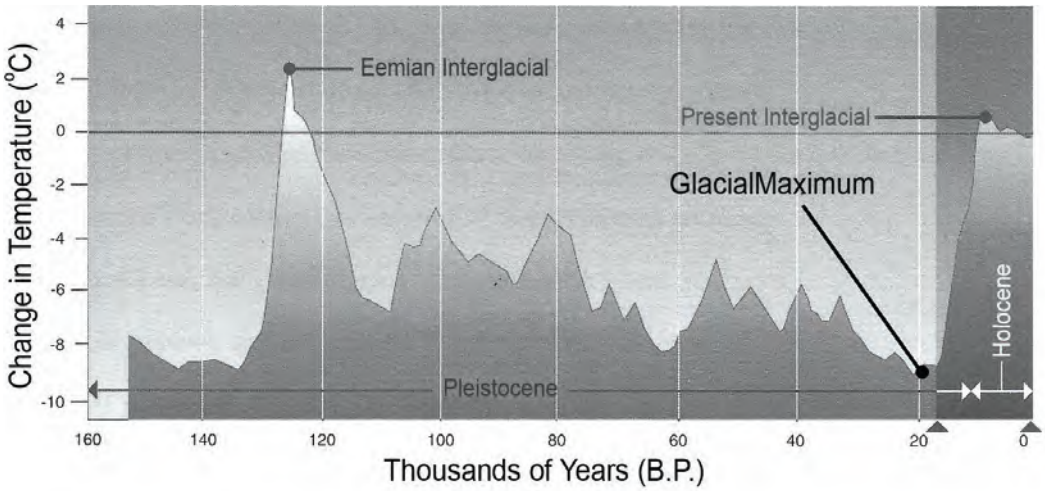

Figure 3-2—Air temperature changes occurring over the Antarctic over the last 160,000 years. Highlighted are two interglacial periods, the present Holocene and warmer Eemian, each are characterized by rapid onsets of warmer temperatures. The coldest period during the late Pleistocene (last 120,000 years) was the Glacial Maximum. Estimates derived from hydrogen/deuterium ratios measured in ice cores (Eddy and Bradley 1991).

How does understanding woodland dynamics and climate change over the past tens of thousands of years help us to understand vegetation management under current and future conditions? Studying past spatial and temporal dynamics of woodlands and shrublands increases understanding about how current and future variations in temperature and precipitation influence woodland and shrubland migration and local extinction. It provides insights into the dynamics between woodlands and sagebrush ecosystems and the primary drivers of woodland expansion, infill, and contraction over the past 200 years. And it provides clues to the potential consequences of climate change in the next 200 years for woodland and shrub communities (sidebar 4).

Sidebar 4
Vegetation Zones
Names of vegetation zones frequently used in the paleobotany literature for the Great Basin and Colorado Plateau are shadscale, desert scrub, lower sagebrush-steppe, woodland, upper sagebrush-steppe, montane forest, and subalpine forest (defined in the Glossary).

A variety of evidence helps us reconstruct prehistorical conditions for temperature, precipitation, and vegetation dynamics over time and space. The evidence includes: geomorphic footprints of glaciers and lake shorelines; pollen and volcanic ashes; diverse sediments from lakes and ponds; macro fossils from packrat middens, dry rockshelters and caves; extinct animal remains; changes in the isotopic 18O/16O ratios of ice cores, plants, and animal bones; and changes in the δ13C and deutereum ratios in plants (Wigand et al. 1994a; Wigand 1999). This evidence is used to determine the presence, persistence, and dynamics of plant species at a given location or region and temporal changes in climate. This combination of evidence allows us to reconstruct the general climate and the elevational/latitudinal movement of pinyon and juniper in response to changes over the past 20,000+ years across the Great Basin and Colorado Plateau. It also allows us to examine changes in associated species and the spatial movement of plant species and their varying community combinations through time.

A limitation of this evidence is the difficulty to differentiate pollen among different sagebrush species and subspecies (Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, Graduate Program of Hydrological Sciences, University of Nevada, Reno, personal communication, 2017), which as a group occurs across a broad range of moistures and temperatures (fig. 3-3). As a result, a number of paleobotany papers simply lump *Artemisia*, which limits moisture and temperature

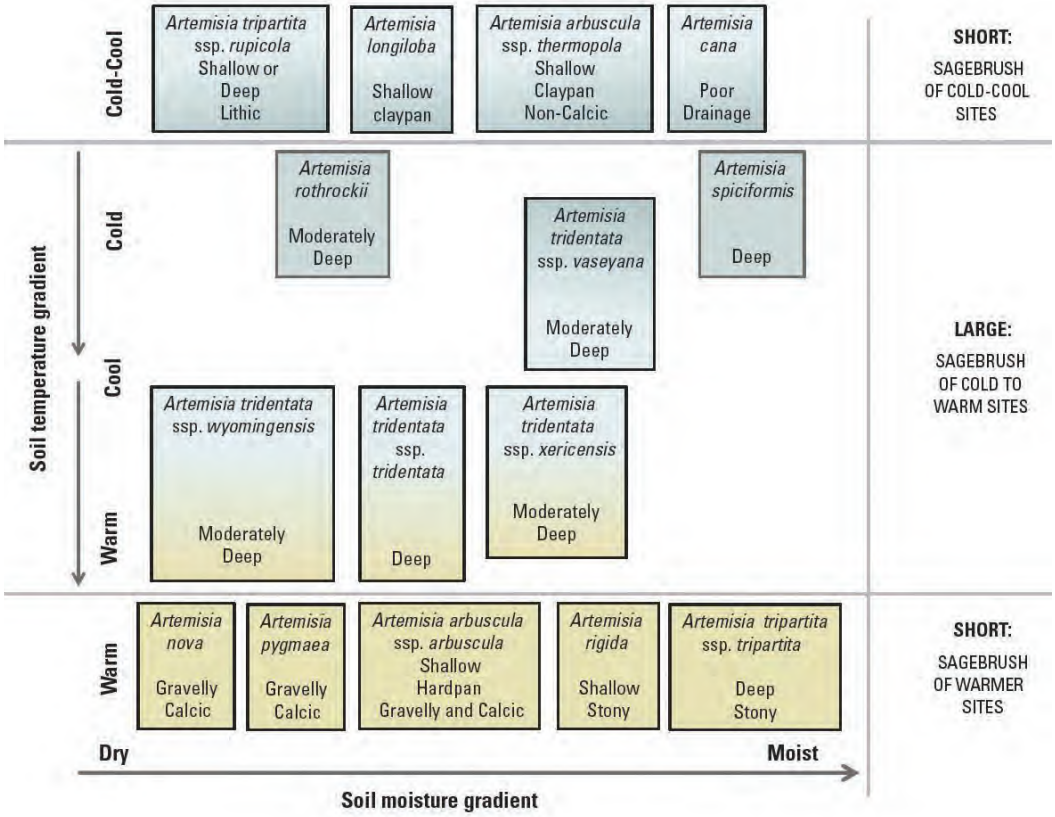

Figure 3-3—Sagebrush taxa in the Great Basin and Columbia Basin positioned along soil temperature and moisture gradients (Pyke et al. 2015). As a group, they occur over a relatively broad moisture and temperature gradient.

interpretations. However, the mention of associate shrub species or elevation placement in relation to the pinyon and juniper woodland zone can help to narrow down the likely Artemisia species or subspecies, which allows for a more accurate interpretation of available moisture. Pinyon and juniper are identified to species in the analysis of geologic evidence, making the reconstruction of their history more straightforward.

Late Pleistocene—20,000 to 10,000 Years Ago

Distribution of vegetation across the Great Basin and Colorado Plateau during the late Pleistocene was dramatically different from presettlement and present-day vegetation. The latter portion of the Pleistocene Epoch includes the last interglacial episode and the last major advance of continental glaciers in North America, which began around 120,000 years ago and ended 10,000 to 11,000 years ago (fig. 3-2; Eddy and Bradley 1991). Temperatures and precipitation fluctuated throughout this epoch with the coldest (the Glacial Maximum) and warmest temperatures (Bølling–Allerød period) during the late Pleistocene (fig. 3-1). The warmest and driest conditions occurred after the Pleistocene in the Holocene during the Thermal Maximum (Renssen et al. 2009).

Climate

The coldest period over the past 120,000 years across the West occurred during the Glacial Maximum (approximately 20,000 years ago) (fig. 3-2) persisting with a gradual temperature increase until 14,500 years ago (fig. 3-1; Davis 1987; Eddy and Bradley 1991; Spaulding 1985; Van Devender and Spaulding 1979; Wells 1983; Woolfenden

1996). Lake Bonneville reached a peak elevation level of 5,102 feet approximately 15,500 years ago, covering 20,000 square miles of northwestern Utah at a depth of 900 feet (Patrickson et al. 2010). The greatest elevation level of Lake Lahontan in Nevada around this same period was 4,370 feet (Morrison 1964) covering more than 8,000 square miles of northwestern Nevada and reaching a depth of 400 feet at Fallon, Nevada.

Temperatures during the Glacial Maximum across the Great Basin were estimated to have been 9.9–12.6 °F cooler than current conditions (Dohrenwend 1984) but varied regionally from north to south and east to west (table 3-1). The temperature variations likely represent a combination of regional differences in climate and are possibly a result of the methodologies used. Bevis (1995) concluded differences in summer temperatures between the Glacial Maximum and current conditions were considerably larger in the northwestern than southcentral Great Basin. In the Tushar Mountains of central Utah (latitude 38°22'19.49"), summer temperatures were 7.2 °F colder than today, but on Steens Mountain in southeast Oregon (latitude 42°44'11.49"), summer temperatures were 16.5 °F colder than today (table 3-1). Bevis concluded mean summer temperature depressions in the southern Great Basin were possibly mediated by increased annual precipitation. Toward the end of the late Pleistocene, precipitation estimates were almost 1.3-fold greater than current levels based on vegetation distributions, Pleistocene lake levels, and the lower glacier boundaries (Bevis 1995; Porter et al. 1983). Between 14,000–13,000 years ago temperatures began to increase more rapidly (Bølling -Allerød period) but still remained cooler than present (fig. 3-1).

Table 3-1—Estimated temperature differences between the last glacial maximum and current conditions from northerly to southerly locations across the Great Basin (adapted from Grayson 2011). MAT = Mean Annual Temperature.

Location	Temperature (°F)	Source of estimate	Reference
Steens Mt, southeast OR	-16.5 summer	Glacier formation	Bevis 1995
Pine Forest Range, northwestern NV	-10.8 summer	Glacier formation	Bevis 1995
Lahontan Region, northwestern NV	-14.4 to -16.2 MAT	Vegetation change	Wigand and Rhode 2002
Ruby Marsh, northeastern NV	-12.6 MAT	Glacier formation	Bevis 1995
Northern Bonneville Basin, northwestern UT	-5.6 to -16.2 MAT	Vegetation change	Davis 2002
Northern Bonneville Basin, northwestern UT	-10.8 to -12.6 MAT	Computer modeling	Laabs et al. 2006
Deep Creek Mountains, northwestern UT	-5.6 summer	Glacier formation	Bevis 1995
Northern Uinta Mt, northcentral UT	-9.9 to -14.4 summer	Glacier formation	Munroe and Mickelson 2002
Western Uinta Mt, central UT	-9 to -12.6 MAT	Glacier formation	Refsnider et al. 2008
Tushar Mts, central UT	-7.2 summer	Glacier formation	Bevis 1995
Southern Nevada	-10.8 winter	Vegetation change	Spaulding 1985
Southern Nevada	-10.8 to -12.6 MAT	Vegetation change	Spaulding 1985
Southern Nevada	-12.6 to -14.4 MAT	Vegetation change	Spaulding 1985
Owens Valley, eastcentral CA	-18 MAT	Plant hydrogen isotopes	Jennings and Elliot-Fisk 1993
Death Valley, southeastern CA	-14.4 to -25.2 summer	Vegetation change	Woodcock 1986

In the Colorado Plateau, estimated temperature differences between the Glacial Maximum (14,000–23,000 years ago) and current were 5.4 to 7.2 °F cooler (Anderson et al. 2000), similar to differences estimated for the southern Great Basin. Glaciers do not exist in the Colorado Plateau today, but during the late Pleistocene they occurred on several ranges with the lower edges dropping to as low as 8,600 feet on San Francisco Peak just north of Flagstaff, Arizona (Anderson et al. 2000). Estimates of annual increases in precipitation during the Glacial Maximum were about 1.5 times that of current (Betancourt 1984). However, summer precipitation may have been less during much of the late Pleistocene (Anderson et al. 2000). There appear to be discrepancies in the literature related to amounts of precipitation during the late Pleistocene. But this is likely related to regional differences. Some authors reported conditions were dry and cold (Brakenridge 1978; Galloway 1970, 1983; Thompson and Mead 1982) and others wet and cold (Wells 1979).

Following the Glacial Maximum, temperatures warmed gradually until the beginning of the Bølling-Allerød period (14,700 to 11,000 years ago) when they warmed rapidly (fig. 3-1). This was a relatively moist period—possibly the warmest in the last 10,000 years of the Pleistocene. Immediately following the Bølling-Allerød period was the Younger Drayas cold snap, a 500-year phase, preceding the onset of the Holocene—11,000–10,000 years ago (Carlson 2013; Eddy and Bradley 1991). In the West, temperatures during the Younger Dryas cold snap cooled more than 5.5 °F and conditions were wetter than the Bølling-Allerød period (Carlson 2013; Cole and Arundel 2005). The transition between the Younger Dryas cold snap and the Holocene was very rapid, with temperatures rising as much as 18 °F in 60 years (Grayson 2011).

Vegetation

Pleistocene vegetation responded to these long-term changes in climate through latitudinal migration, changes in elevation and aspect, and extinction. During the late Pleistocene Epoch, vegetation across much of the Intermountain West was dominated by plant species present in the region today (Grayson 2011; Nowak et al. 1994a,b, 2017; Spaulding 1990; Thompson 1990). Sagebrush, snowberry, cinquefoil, saltbush, greasewood, and many grass and forb species common today were present during the Pleistocene. The most abundant and frequently occurring plant group in pollen and macro fossil records is sagebrush (Grayson 2011). However, in the northerly latitudes of their current ranges (with the exception of Utah juniper), pinyon pines and western juniper were absent during the Pleistocene Epoch (Thompson et al. 1986; Wigand and Nowak 1992).

The likely reason many species in the semiarid Intermountain West persisted throughout the Holocene and Pleistocene is the highly variable topography and the mountain ranges oriented predominately north and south. This variability allowed plant species to stay within their moisture and temperature ranges by migrating up or down in elevation and/or across aspects and more easily moving north and south. Over the past 20,000 years, some species shifted as much as 3,000 feet in elevation (fig. 3-4; Spaulding 1990). These shifts appear have been greater in the south than the north, possibly a result of lower elevation permanent snowpacks in the north. During the Glacial Maximum, subalpine woodlands (typically composed of bristlecone, limber or whitebark pine, and occasionally Engelmann spruce; see Glossary for the use of the term subalpine woodlands) were considerably more extensive than they are today. Subalpine woodlands occupied mid- and lower- slopes of the Great Basin and Colorado Plateau where pinyon and juniper woodlands commonly occur today (Spaulding 1985; Thompson 1990; Thompson and Mead 1982; Van Devender and Spaulding 1979; Wells 1983; Wigand et al. 1995; Woolfenden 1996).

Wells (1983) argued that subalpine woodlands even occupied the valley floors. However, Thompson (1990) suggested these Pleistocene woodlands were restricted to coarse-textured soils of the mountain slopes, and expansion into the fine-textured

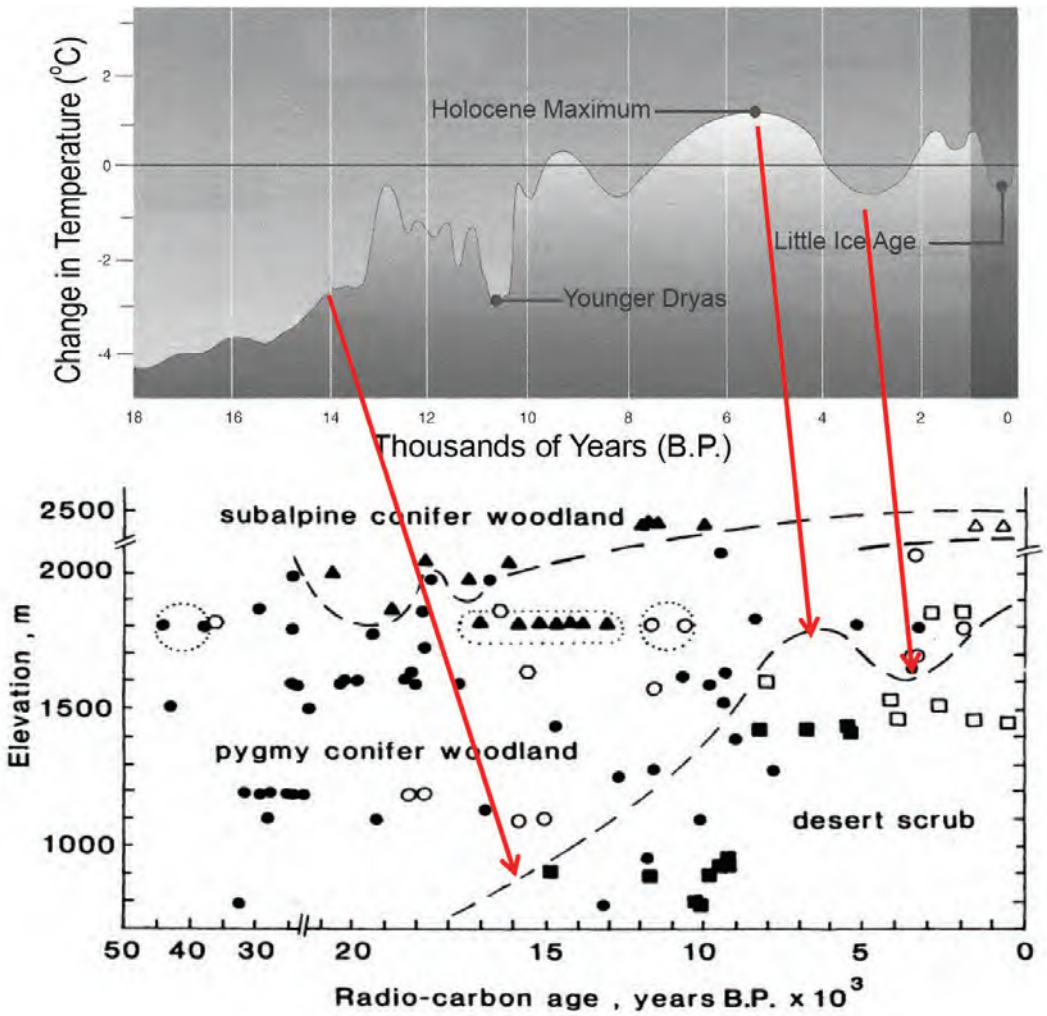

Figure 3-4—Pleistocene and Holocene elevation changes for pinyon, juniper, and subalpine conifer woodlands in the northern Mojave Desert based on woodrat middens. Subalpine woodlands (solid black triangles), subalpine woodlands with abundant Utah juniper (open triangles), Utah juniper (solid black circles), and mixed Utah juniper and pinyon pine (open circles) (modified from Spaulding 1985; Eddy and Bradley 1991).

valley floors was limited. Today, the lower boundary of juniper in the Basin and Range of Nevada and western Utah commonly occur near the toe-slopes where moisture is sufficient, but they also often extend along the concave depressions of the drainages, which reach out into the valley floors. It is clear that white fir (*Abies concolor* (Gord. & Glend.) Lindl. Ex Hildebr.) descended in elevation in the Paranagat Range north of Las Vegas, Nevada, and disappears from record around the Lake Lahontan area around the Glacial Maximum. White fir also remained present at lower elevations in mountains of the Nevada Test Site as late 11,000 years ago (Wigand 2017).

Subalpine woodlands were largely open, with abundant understory communities, often with sagebrush (possibly mountain big sagebrush) as the dominant or subdominant shrub (Thompson 1990). Even today it is not uncommon to observed subalpine woodlands intermingle with high elevation sagebrush communities. Subalpine tree species common in the southern and eastern portions of the Great Basin and Colorado Plateau included bristlecone pine, limber pine, common juniper, Engelmann spruce, and Rocky Mountain juniper. Bristlecone pine was most prominent, based on its relative abundance in material from packrat middens.

In the northwestern Great Basin, common conifer species were whitebark pine, creeping juniper, and common juniper (Wigand et al. 1994b). In the northwestern portion of its range, Utah juniper persisted near its current latitudinal limit at the lower elevations. However, at higher elevations in Utah, its northern limit was where the Green River enters the Colorado River (Anderson et al. 2000), nearly 450 miles south of its current northern boundary. In the Ruby Mountains and Snake Range in central and eastern Nevada and the western shores of Lake Bonneville, Utah juniper was either uncommon or absent (Thompson 1990, 1992).

A major difference in conifer geographical distribution between the Pleistocene and Holocene was the absence of three tree species common today. During the Glacial Maximum, both singleleaf and twoneedle pinyons were located at the very southern edge of their current range (fig. 3-5; Cole et al. 2013). And there is no evidence of western juniper occurring in the Great Basin until the very end of the late Pleistocene (Nowak et al. 1994a; Thompson et al. 1986).

Subregions

Northwestern Great Basin (Klamath and Shasta Valleys and Basins, and Malheur High Plateau; MLRAs 21 and 23)

Late Pleistocene landscapes were predominately shrub dominated by sagebrush intermixed with other shrub species adapted to colder environments. Associated species included creeping and common juniper (Wells 1983; Wigand et al. 1994b) and possibly other cold adapted shrubs such as mountain and/or low sagebrush, snowberry, cinquefoil, currant, and rabbitbrush. There appeared to be a complete lack of junipers with a tree growth form, pinyon or subalpine woodland tree species occurring this far north. The oldest pollen record in the area is from deep sediment cores at Tulelake in northeastern California. Pollen abundance and ratios suggest sagebrush has been present and probably a dominant component of the vegetation for over 1 million years (Woolfenden 1996). Evidence of creeping and common junipers were found in the Owyhee River Valley 27,000 years ago, near the border of Oregon and in Idaho southwest of Boise, Idaho (Wells 1983), and possibly near Summer Lake in eastern Oregon between 12,000 and 50,000 years ago. The presence of these two low-growth form juniper species strongly suggests a colder and wetter climate than current conditions. Depending on soil characteristics, these two conifers were likely associated with mountain big and low sagebrush.

There is no evidence of western juniper occupying its current range during the Pleistocene, nor did it occur farther south in the Great Basin. The earliest evidence of western juniper (12,070 years ago) was found on the northeastern shores of Winnemucca Lake, south of its current range (Thompson et al. 1986; Wigand and Nowak 1992). A possible refugium for western juniper during most of the Pleistocene may have been in the foothills and low mountains surrounding the northcentral valley of California (Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, University of Nevada, Reno; Robin Tausch, Retired Range Scientist, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada; and Rick Miller, Professor Emeritus Range Ecology, Oregon State University, Corvallis, Oregon, personal discussion, 1998). Partially supporting this hypothesis is the lack of Utah juniper DNA markers in western juniper in this area today, suggesting a long-term isolation between the two species (Terry et al. 2000). East of the Cascades, Utah juniper DNA markers are commonly found in western juniper.

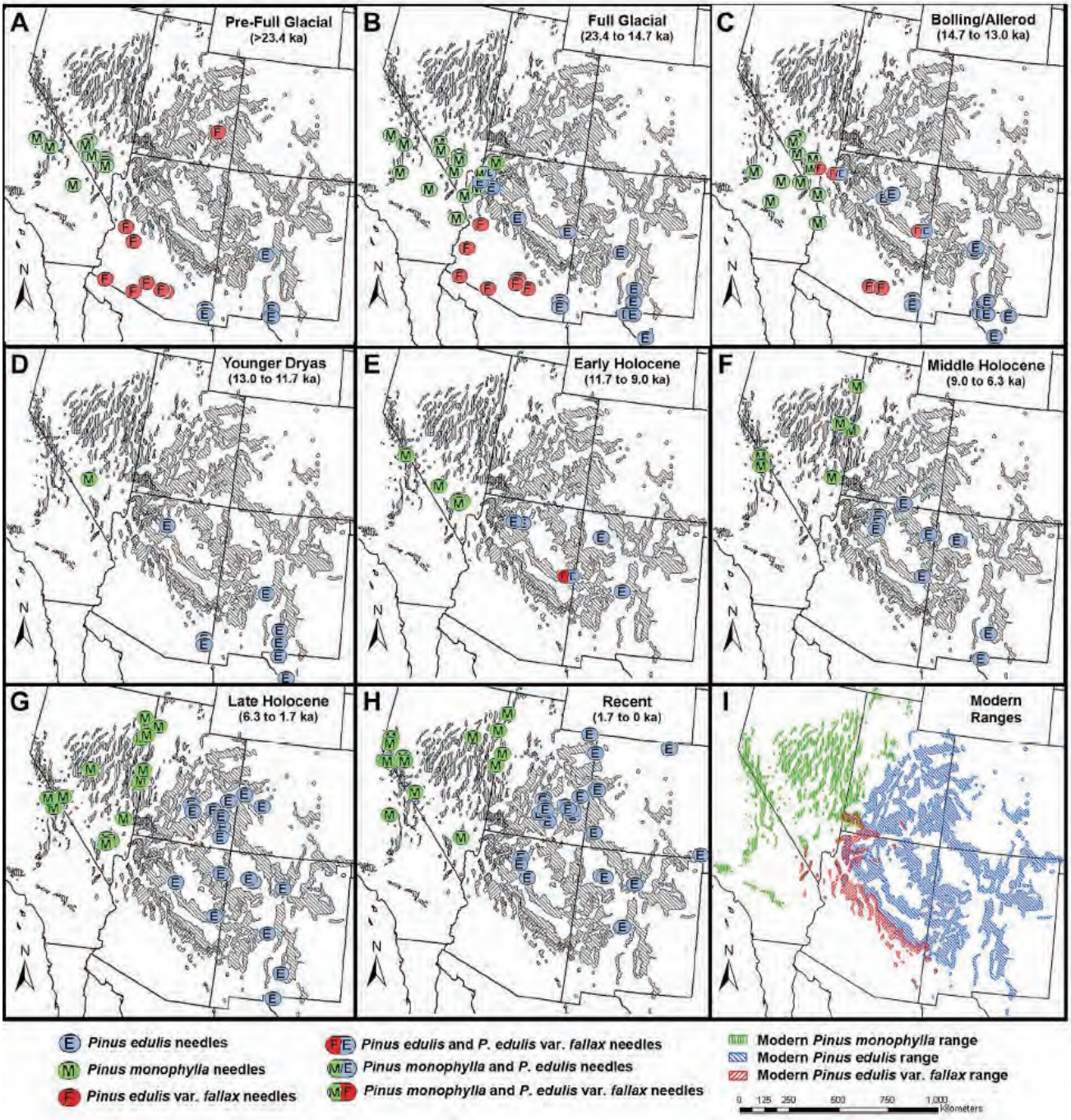

Figure 3-5—Fossil records of pinyon types obtained from packrat middens spanning eight time periods (A-H) as compared to modern ranges (gray background patterns) and (I) modern ranges of two pinyon species and one subspecies (Cole et al. 2013).

West-Central Great Basin (Carson Basin and Mountains, and Fallon-Lovelock; MLRAs 26 and 27)

Sagebrush was present throughout the late Pleistocene in the west-central Great Basin as well (Grayson 2011; Nowak et al. 1994a,b). Under these wetter and cooler conditions, it dominated areas above late Pleistocene lake levels now occupied by *Atriplex* species and greasewood (Nowak et al. 1994a,b). However, unlike the northwestern Great Basin, temperatures appeared to be moderate

enough for trees to occupy this region. Between 30,000–12,500 years ago, the lower elevational treelines of subalpine (primarily whitebark pine with some limber pine) and Utah juniper woodlands were 3,300–3,600 feet lower than today (fig. 3-6; Nowak et al. 1994b; Wigand and Nowak 1992). Semiarid woodlands were composed of Utah juniper with an abundant understory of sagebrush. Pinyon pine was absent and remained so until the late Holocene (Cole et al. 2013; Nowak et al. 1994b). The lower band of juniper woodlands occupied the landscape below 4,250 feet until around 9,500 years ago when they were replaced by semiarid steppe or semiarid shrublands (Wigand and Nowak 1992). At the mid-elevations above 4,250 feet, Utah juniper has changed little in the fossil record (Nowak et al. 1994a,b).

In the Carson Sink area sagebrush was the dominant plant and Utah juniper was present throughout the late Pleistocene—where Atriplex species are common today (Grayson 2011). Limber pine and curlleaf mountain mahogany were also present in the area, growing more than 3,000 feet below their current elevation range. The northeast end of Winnemucca Lake may have been one of the early arrival points of western juniper into the Great Basin 12,500 years ago (Thompson et al. 1986). Cool season grasses common in the area today were also present throughout the late Pleistocene as were sagebrush and mountain mahogany (Nowak et al. 1994b). Whitebark pine was also abundant at lower elevations close to the Pleistocene high stand of Pluvial Lake Lahontan in the Virginia Mountains from about 22,000–11,000 years ago, where it was mixed with Utah juniper and mountain mahogany (table 3-2; Wigand and Nowak 1992).

Figure 3-6—The range of Utah juniper has shifted little in latitude over the past 30,000 years in the westcentral part of the Great Basin as compared to the central and eastern Great Basin. However, it has moved up and down in elevation by more than 3,000 feet in response to climate in the western Great Basin. Relict woodland in the Virginia Mountains, Nevada. (Photo by Robin Tausch, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada.)

Table 3-2—Estimated upper elevational boundaries for woodlands in the southern portion of the Great Basin (Mojave Desert) during the late Pleistocene to present day (derived from Anderson et al. 2000; Spaulding 1985, 1990; USDA-NRCS plant guide).

Woodland type	Elevation (ft)	Years ago
Pygmy woodland	4,560	18,000 glacial max
	5,248	16,000
Singleleaf pinyon pure stands	< 9,200	Present
Utah juniper	1,200–3,300 (6,600)	18,000 glacial max
	2,500–3,000	13,200–11,700
	4,260–6,600	9,000
	5,900–7,200	Present
Temperate desert scrub	3,900–5,900	Present
Hot desert scrub	< 3,900	Present

Great Salt Lake and Central Nevada Basin and Range (MLRAs 28a, b)

Subalpine woodlands were an important component in the Snake, Wah Wah, and Confusion ranges of the eastern Great Basin during the late Pleistocene (Thompson 1984, 1990; Wells 1983). They were a common component of vegetation on the lower mountain slopes, 2,200 to 2,750 feet lower than today (Thompson 1984). Subalpine woodlands may have extended across the valley floors—based on the elevation of material found in a midden located in a wash (Wells 1983). But Thompson (1984) argued subalpine woodlands were largely restricted to the mountain slopes growing on the coarse-textured soils. Wigan reported bristlecone pine was located just above the valley floor in the Egan Range of eastern Nevada (Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, University of Nevada, Reno, personal communication, 2019).

Subalpine woodlands formed a continuous matrix with sagebrush ecosystems throughout this region (Thompson 1990) and were largely composed of bristlecone pine, limber pine, common juniper, and—in the Snake Range—Engelmann spruce. Rocky Mountain juniper first appears in the midden samples right after the Glacial Maximum, around 17,000 years ago. Utah juniper was present in the early Wisconsin Glacial Period, 30,000+ years ago—however, it appears to be absent during full glaciation, not returning until around 14,000 years ago and then becoming relatively abundant during the Holocene (Thompson 1990). Cold temperatures rather than precipitation possibly were the primary factor limiting the distribution of Utah juniper during the late Pleistocene.

Farther north, between 30,000–10,000 years ago, woodland species were uncommon or absent across much of the northern portion of the central Great Basin (i.e., the Ruby Mountains and Ruby Marsh) (Thompson and Mead 1982). Sagebrush species were common, and only limited pine (no species named) occurred in the area. However, just to the east on the western shores of Lake Bonneville, Engelmann spruce and limber pine were common between 17,000–14,000 years ago. A combination of lower elevations and possible lake-effect on climate may have resulted in more moderate temperatures, allowing conifers to survive. Prior to the Glacial Maximum more than 40,000 years ago, Utah juniper was present and associated with sagebrush, snowberry, and horsebrush in the Goshute Mountains, just west of Lake Bonneville and 30 miles to the east of the Ruby Mountains. But Utah juniper generally declined in the northern portions of this region during the onset of the Wisconsin period and then disappeared—reappearing around 8,000 years ago (Grayson 2011). Mountain shrub, composed of sagebrush and snowberry, were common on the lake shores, becoming dominant 14,000–13,000 years ago, and suggesting significantly greater moisture than today (Grayson 2011; Thompson 1990).

Southern Nevada Basin and Range and High Mountains of the Mojave (MLRA 29, 30)

During the Glacial Maximum, the midden record indicates Utah juniper woodlands were the dominant vegetation type at elevations now occupied by desert shrubs (Jennings 1988, 1995). This is about 2,000 feet lower than where pinyon and juniper woodlands are found today (Jennings and Elliot-Fisk 1993). Desert shrub communities were found only east of the double rain shadow created by the Sierra Nevada and the White and Inyo mountains. Although Utah juniper was the most abundant tree in semiarid woodlands, pinyon did occur infrequently in the upper portions of these woodlands between 3,300 and 5,900 feet, converting to subalpine woodland at the higher elevations (fig. 3-7a,b; Spaulding 1983, 1985; Wells 1983).

During the Glacial Maximum, Utah juniper was growing down to a 1,200 feet elevation (fig. 3-4; Spaulding 1990). Although Utah juniper was typically the dominant tree (Grayson 2011), the southern Nevada Basin and Range formed the northernmost distribution of singleleaf and twoneedle pinyon pines (fig. 3-5; Cole 1990; Cole et al. 2013; Spaulding 1990). Singleleaf pinyon was growing, at times, at the southern end of the Owens Valley, on the east slopes of the Sierras, and the Sheep and Spring mountains in the Mojave near Las Vegas, Nevada (Cole et al. 2013). In the Mohave, Utah juniper and pinyon pine occupied mountain ranges that no longer support conifers today. Examples are the Hidden Hills north of Las Vegas and the Tinajas Atlas Mountains just southeast of Yuma (Davis 1987; Wells and Jorgensen 1964). In the Owens Valley near the Owens Lake shoreline, middens dating back more than 30,000 years showed that Utah juniper occupied the area in the late Pleistocene (Koehler and Anderson 1994, 1995) and both pinyon and juniper 11,450 years before present (Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, University of Nevada, Reno, 2019). However, by 9,000 years ago it disappeared from the valley floor moving upslope—from less than 4,500 feet to over 6,200 feet. Rocky Mountain juniper was also found in the Owens Valley 17,500–16,000 years ago (Koehler and Anderson 1994). It is no longer found in California and the nearest population today is in the Spring Range near Las Vegas, Nevada, 140 miles to the east (Charlet 1996).

Temperatures gradually increased following the peak of Glacial Maximum with dramatic increases in temperatures occurring during the onset of the Bølling-Allerød period, 14,700–13,000 years ago (fig. 3-1). Pinyon and juniper responded by migrating upward in elevation, replacing the subalpine species and forming semiarid woodlands (table 3-2; Spaulding 1990). Toward the end of the late Pleistocene, 10,000–12,000 years ago, vegetation mosaics of woodland on the northerly and desert scrub on the southerly aspects occurred below 3,300 feet (Spaulding 1990; Wells and Woodcock 1985). Today, these areas are occupied by desert scrub while pinyon and juniper woodlands occupy areas that had been covered with subalpine woodlands made up of limber and bristle cone pines and understories of sagebrush (Spaulding 1990).

Colorado Plateau (MLRA 35)

During the Glacial Maximum, plant species and vegetation zones were growing 2,000–3,300 feet lower than today (Anderson et al. 2000; Coats et al. 2008; Cole 1985). The timberline dropped to around 8,500 feet (today it is at more than 11,000 feet) and subalpine tree species, largely Engelmann spruce and subalpine fir, grew above 7,200 feet (today they grow at 10,000–11,500 feet). The mixed conifer forest, largely composed of limber pine, Douglas-fir, white fir, Rocky Mountain juniper, and occasionally blue spruce, was probably the most extensive forest in the Colorado Plateau during full glaciation. These forests were commonly found between 5,200 and 6,900 feet (Anderson et al. 2000) but in some areas extended down to 4,500 feet (Cole 1985) and occupied much of the area that is currently occupied by ponderosa pine. Mixed conifer forest was typically open with associated understory species including big sagebrush, rabbitbrush,

Figure 3-7—During glacial maximum, Utah juniper dominated the semiarid woodlands between 3,300 and 5,900 feet on the White Mountains of California. Pinyon was a minor component during the late Pleistocene. Today, pinyon and juniper woodlands occur between (A) 6,500–9,500 feet where bristlecone and limber pine occurred 20,000 years ago. At near 11,000 feet, the limber and bristlecone pines intermingle with mountain big sagebrush communities. (B) During glacial maximum, these bristlecone and limber pine woodlands grew 3,000 feet lower where pinyon and juniper woodlands now occur. White Mountains, California. (Photo by Rick Miller, Oregon State University.)

rose, and skunkbush sumac. Juniper woodlands often dominated the lower elevations below the mixed conifer forests. The juniper-shadscale-sagebrush zone in the western Grand Canyon occurred at elevations from 4,800–6,200 feet (fig. 3-8; Cole 1985) and in the eastern Grand Canyon at elevations up to 4,750 feet (Anderson et al. 2000). In the central portion of the plateau near Canyonlands, juniper woodlands present before the Glacial Maximum were replaced by mixed conifer during the Glacial Maximum (Anderson et al. 2000). The mixed conifer woodlands were associated with an understory of big sagebrush, rubber rabbitbrush, and species in the rose family. As conditions warmed following the Glacial Maximum, Utah juniper and serviceberry replaced the mixed conifer woodlands by the Bølling -Allerød period, 12,550–11,000 years ago.

Juniper woodlands were largely composed of Utah juniper, mixing with oneseed juniper in areas where summer precipitation was more than 30 percent of the total, and Rocky Mountain juniper occupied the cooler and moister sites (fig 2-4a). Twoneedle pinyon pine was absent across most of the northern Colorado Plateau during the late Pleistocene. Its northern limit occurred along the Mogollon Rim in northwest Arizona extending into central New Mexico then south to western-most Texas (fig. 3-5b; Cole et al. 2013). There is only one record of twoneedle pinyon occurring in the Colorado Plateau prior to the Holocene in the Wupatki National Monument, just north of Flagstaff, Arizona, 16,300–12,800 years ago (Anderson et al. 2000). There is no indication of northward movement during the late Pleistocene.

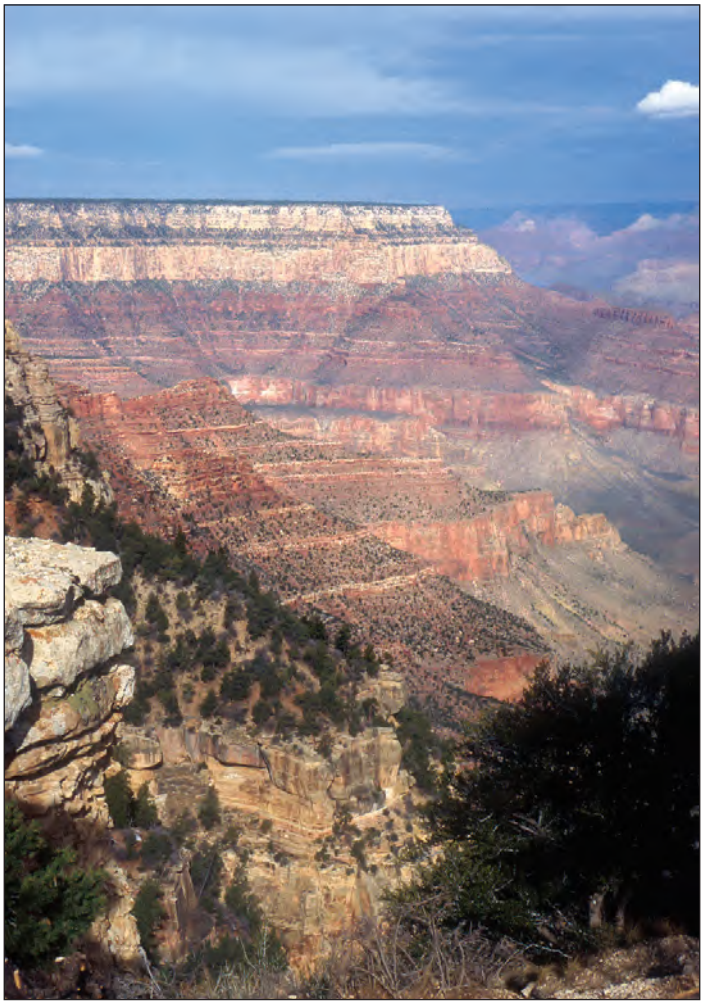

Figure 3-8—The juniper-shadscale-sagebrush zone in the western Grand Canyon occurred at elevations up to 6,200 feet and in the eastern Grand Canyon 4,750 feet during glacial maximum, below where they occur today. Grand Canyon, Arizona. (Photo by Rick Miller, Oregon State University.)

Although there were some similarities in conifer migration in the Colorado Plateau and Great Basin during the colder and wetter climate conditions of the late Pleistocene, there were also some distinct differences. Unlike the northwest Great Basin, where Utah juniper appeared to stay in place latitudinally (fig. 3-6; Nowak et al. 1994a,b), its northern boundary in the Colorado Plateau was over 400 miles south of the northeast edge of its range today. Utah juniper did persist throughout the late Pleistocene across portions of the Colorado Plateau (Coats et al. 2008). Like the Great Basin, sagebrush in the Colorado Plateau has been present in the area well over 50,000 years, and it frequently was a codominant species in the understory of both mixed conifer and juniper woodlands. However, conifer species were more diverse and abundant in the Colorado Plateau than the northwestern and west-central Great Basin. In both the southeastern Great Basin and Colorado Plateau, subalpine woodlands were probably the most important woodland and were composed of limber pine and bristlecone. But in the Colorado Plateau, Engelmann spruce and subalpine fir also became more common in both the subalpine and in mixed conifer at lower elevations.

Holocene 10,000 Years to A.D. 1800s

This section focuses on the distribution shifts of pinyon and juniper woodlands and associate vegetation zones between the end of the late Pleistocene and before Eurasian settlement. Later in this section we will look at the combined impacts of climate and anthropogenic disturbances on woodlands over the past 200 years. The beginning of the Holocene is frequently debated but generally accepted to be around 10,000 years ago (Grayson 2011; Spaulding 1990) immediately following the Younger Dryas cold snap (fig. 3-1). This was a period of warm and dry conditions as Pleistocene lakes and glaciers retreated across the Great Basin and Colorado Plateau. This was also the beginning of relatively rapid elevational and latitudinal migrations of plant species (Cole 1985; Grayson 2011; Wigand et al. 1995) and local extinctions (Nowak et al. 2017). Although the Holocene marked the beginning of warmer and drier conditions, moisture and temperature varied widely across the region in both time and space throughout the period (Eddy and Bradley 1991). Long-term shifts in climate distinguish the early, mid, and late Holocene periods, all of which had significant impacts on local plant species distributions.

Climate in Holocene Period

Climate: Early Holocene 10,000–7,500 years ago

The early Holocene was considerably warmer than the late Pleistocene but was generally cooler and wetter than the mid and late Holocene (fig. 3-1; Antevs 1948; Bedwell 1973; Grayson 2011; Wigand 2017; Wigand et al. 1994a,b, 1995, 2017). Pluvial lake levels dropped—but there were many shallow lakes and marshes that today are smaller, shallower, or dry (Bedwell 1973; Benson et al. 1990; Grayson 2011; Morrison 1964). The highest water levels in Lake Lahontan during the Holocene Epoch occurred between 10,000–8,000 years ago (Morrison 1964). But changes in lake levels were not synchronous across the Great Basin, indicating geographic variations in temperature and/or moisture conditions. The Warner Mountains and Chewaucan Basin in the northwestern Great Basin were drier in the very early part of the early Holocene (approximately 9,000 years ago) (Minckley et al. 2007) as were the Sierra Nevada Mountains (Grayson 2011). Eventually the northwest and western Great Basin became cooler and wetter, as reflected by increased lake levels. Native American populations were at their highest densities throughout the Great Basin during the early Holocene, based on evidence of the frequency of high cave occupancy across the Great Basin, and abundance of middens at cave sites. This is likely a result of relatively

moister conditions leading to more abundant resources (Aikens 1993; Bedwell 1973). Although there are no Pleistocene lakes in the Colorado Plateau, the presence and absence of various plant species at different elevations indicate this region was also generally wetter and cooler during the early Holocene than today (Cole 1990).

Climate: Mid Holocene (Holocene Maximum) 7,500–5,000 years ago

The mid Holocene, which began around 7,500 years ago and persisted for 2,500 to 3,000 years, represents the driest and warmest period in the past 10,000 years (fig. 3-1; Jennings and Elliot-Fisk 1993; Wigand et al. 1995; Woolfenden 1996). In the northern Great Basin, there was a decrease in both summer and spring precipitation around 5,500 years ago (Wigand 2017). Lake levels dropped below current levels and, in many instances, became totally desiccated (Allison 1982; Antevs 1938, 1948; Hansen 1947; Morrison 1964; Reveal 1979; Thompson 1990).

The transition from the early Holocene to mid Holocene and warmer, drier conditions was not abrupt—and there was wide regional variation in timing and rates of contracting lakes levels across the Great Basin. However, between 7,000–6,000 years ago, the entire Great Basin and Colorado Plateau were dry (Cole 1990; Grayson 2011; Wigand 2017) and 2–3 ˚F warmer than at present (Eddy and Bradley 1991). This shift in climate resulted in a rapid change in the spatial distribution of plant species (Cole 1990). Plant communities moved upward in elevation to adjust to the warmer and drier conditions (Grayson 2011). In southeastern Oregon, fossil evidence from human-inhabited caves indicated diets and fuel wood shifted from plants and mammals occupying moist habitats—i.e,. waterfowl, aquatic plants, and ponderosa pine—to animals and plants occupying dry habitats—jackrabbits and sagebrush (Aikens 1993; Bedwell 1973). Many caves in the driest regions of the Great Basin were abandoned and human populations across the Great Basin declined as well (Bedwell 1973; Morrison 1964).

Climate: Late Holocene 5,000 years Ago to 1850

The mid Holocene drought (Holocene Maximum) ended and the moister late Holocene began around 5,500–4,500 years ago. Conditions initially remained warm, but summer and winter precipitation increased (fig. 3-1; Davis 1982; Grayson 2011; Wigand et al. 1995). Although the late Holocene was generally cooler and wetter than the mid Holocene, variations in temperatures and precipitation continued, resulting in elevational and latitudinal shifts in vegetation. The late Holocene is frequently separated into different periods, which characterize general climate trends (table 3-3). During the Neoglacial period, climate conditions across the Great Basin began to cool and moisture increased, especially in the northern Great Basin (fig. 3-1; Davis 1982; Grayson 2011; Wigand 2017; Woolfenden 1996). The Great Salt Lake reached its highest level 3,400 and 2,000 years ago since the early Holocene 21 feet above its present-day average (Grayson 2011).

The timing of transition from the Neoglacial to the drier and warmer post-Neoglacial period (2,500 to 2,000 years ago) varied regionally across the Great Basin and Colorado Plateau—but increasingly arid conditions became widespread by 2,000 years ago (fig. 3-1; Chatters and Hoover 1992; Eddy and Bradley 1991; Miller et al. 2001). Data indicate that climate became increasingly variable after 2,600 years ago and that episodes of drought occurred in some areas in the Great Basin, while other areas were wetter than current conditions. Water levels in the Carson Sink in Nevada, Diamond Pond in southeast Oregon, and Pahranagat Lake in southern Nevada were higher 2,300 years and 2,000 years ago than today (Grayson 2011; Wigand 1987; Wigand et al. 1995).

But evidence suggests the middle reaches of the Humboldt River were dry 2,400 years ago (Miller et al. 2001) and chenopod pollen (species adapted to arid conditions) increased 2,500 to 2,000 years ago in the Pyramid Lake area (Mensing et al. 2004).

Table 3-3—General climate conditions during different periods in the late Holocene (derived from Grayson 2011; Wigand et al. 1995). Numbers in parentheses are other reported estimates, typically varying with geographic region.

Period	Time	Climate
Early-Late Holocene	5,500–4,000 years ago	Drought ends but stays warm
Neoglacial	4,000–2,500 (2,000) years ago	Wet and cool
Late Holocene Dry	2,500 (2,000) to 1,300 years ago	Dry and warming
Medieval Warm	A.D. 900–1350	Dry and warm
Little Ice Age	1350–1850	Cooled off with variable moisture availability
Early postsettlement	1850–1920	Generally wet
Late postsettlement	1920–present	Generally warmer and drier
Temperate desert scrub	3,900–5,900	Present
Hot desert scrub	< 3,900	Present

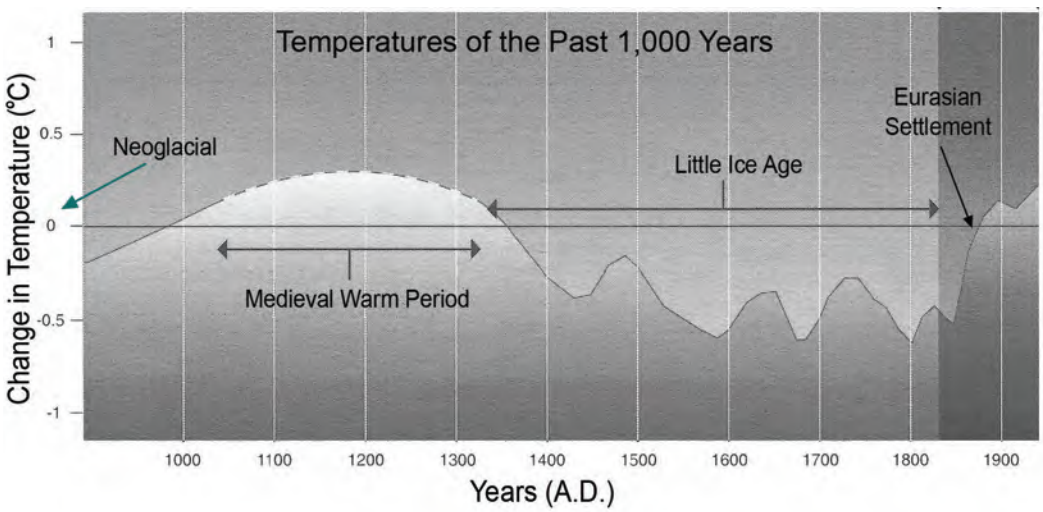

Figure 3-9—Global surface air temperature changes from A.D. 1000–1900. Highlighted is a possible protracted warming through the Medieval period followed by much colder conditions, loosely termed the Little Ice Age. Temperatures estimated from a variety of sources including tree rings and written records (Eddy and Bradley 1991).

Wigand and Rhode (2002) suggested an increase in summer precipitation about 2,000 years to 1,900 years ago may have favored the expansion of pinyon pine in the western Great Basin. Increasing temperatures and continued dry conditions characterized the shift to the Medieval Warm Period between 900 and 1350 CE (common era). Although this period was relatively warm and dry, it was not as severe or as long in duration as the mid Holocene (figs. 3-1, 3-9; Eddy and Bradley 1991; Grayson 2011). The 4 most severe droughts in the past 1,200 years occurred during the Medieval Warm Period and were drier than any 20th century droughts (Cook et al. 2004).

Tree-ring studies in the southern Sierras also revealed temperatures exceeded those of the late 20th century (Graumlich et al. 1995). The Medieval Warm Period ended abruptly around 600 years ago followed by the Little Ice Age. The Little Ice Age was a relatively cooler and initially wetter period than current conditions. Glaciers expanded in the Sierras and did not retreat until the early 1900s (fig. 3-9; Eddy and Bradley 1991; Graumlich 1993; Grayson 2011; Stine 1996). Upper treelines were at their lowest since the end of the early Holocene (Stine 1996). The first half of this period was generally

cool and moist while the second half was cool and dry (LaMarche 1974; Grissino-Mayer and Swetnam 2000; Wigand et al. 1995). Researchers attribute the cool temperatures during this period to 16 different volcanic eruptions between 1630 and 1850, including the Tambora eruption in 1815, which resulted in the year without summer in 1816 (Bradley and Jones 1993).

Vegetation in Holocene Period

Vegetation: Early Holocene 10,000–7,500 Years Ago

Just prior to the onset of the early Holocene, pinyon pines retreated south during the Younger Dryas cold snap—evidence that the cold temperatures restricted movement northward (Cole et al. 2013; Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, Nevada, Reno, 2018). During the initial portion of the early Holocene, both pinyon species resumed their northern migration.

In the western portion of the Great Basin, the northern boundary of singleleaf pinyon was the south end of the Inyo Mountains (fig. 3-5e; Cole et al. 2013; Grayson 2011). By 9,000 years ago, singleleaf pinyon entered the area of the White Mountains but remained a minor component of the tree canopy, which was dominated by Utah juniper (fig. 3-10; Jennings 1988, 1995). Today pinyon is the dominant woodland tree. In the central Great Basin, singleleaf pinyon migrated rapidly north along the Nevada and Utah border during the transition from the early to mid Holocene (fig. 3-F) (Cole 1985; Cole et al. 2013). Western juniper first appeared in the Great Basin around 12,070 years ago on the shrinking northwest shores of Winnemucca Lake just north of Reno, Nevada (Nowak et al. 1994a; Thompson et al. 1986). This is well south of its current range, where it remained absent throughout the early Holocene. In the Colorado Plateau, twoneedle pinyon's northern boundary remained south of the Utah and Colorado borders as late at 6,300 years ago (fig. 3-5e, f; Anderson et al. 2000; Cole et al. 2013). Relatively cooler temperatures during the early Holocene likely limited the northward migration of both pinyon species (Grayson 2011; Nowak et al. 1994a).

Vegetation: Mid Holocene 7,500–4,500 Years Ago

The driest and warmest period of the mid Holocene resulted in the upward movement of pinyon and juniper woodlands by as much as 1,500 feet in the Great Basin and Colorado Plateau (fig. 3-1; Cook et al. 2004; Grayson 2011; Jennings and Elliot-Fisk 1993; LaMarche 1973; Wigand et al. 1995; Wigand and Nowak 1992; Woolfenden 1996). In the northwestern Great Basin, Utah juniper retreated upslope but remained near its current latitudinal range. Sagebrush replaced Utah juniper at its lower boundary (Wigand et al. 1994b). However, in the Colorado Plateau and central Great Basin, Utah juniper, which occurred 400 miles south of its current range during the Glacial Maximum, moved north during the mid Holocene (Anderson et al. 2000; Lyford et al. 2003).

There was very limited northward migration of singleleaf pinyon along the east slopes of the Sierras that appeared to move and stop, responding to variable climate (fig. 3-10; Wigand 2017). But migration north continued rapidly into the central Great Basin along the Nevada and Utah border (fig. 3-5e, f; Cole et al. 2013; Grayson 2011; Nowak et al. 1994a). By 6,800 years ago, singleleaf pinyon moved into the Schell Creek and Pequop Mountains but remained absent 30 miles west in the Ruby Mountains. Movement of singleleaf pinyon northward along the Nevada and Utah border may have resulted from milder winter temperatures. Avoidance of more arid conditions during this period may have led to migration northward along higher elevations. Several researchers have reported that cold winter conditions likely limited movement of pinyon species northward (Grayson 2011; Nowak et al. 1994a; Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, University of Nevada, Reno, 2018).

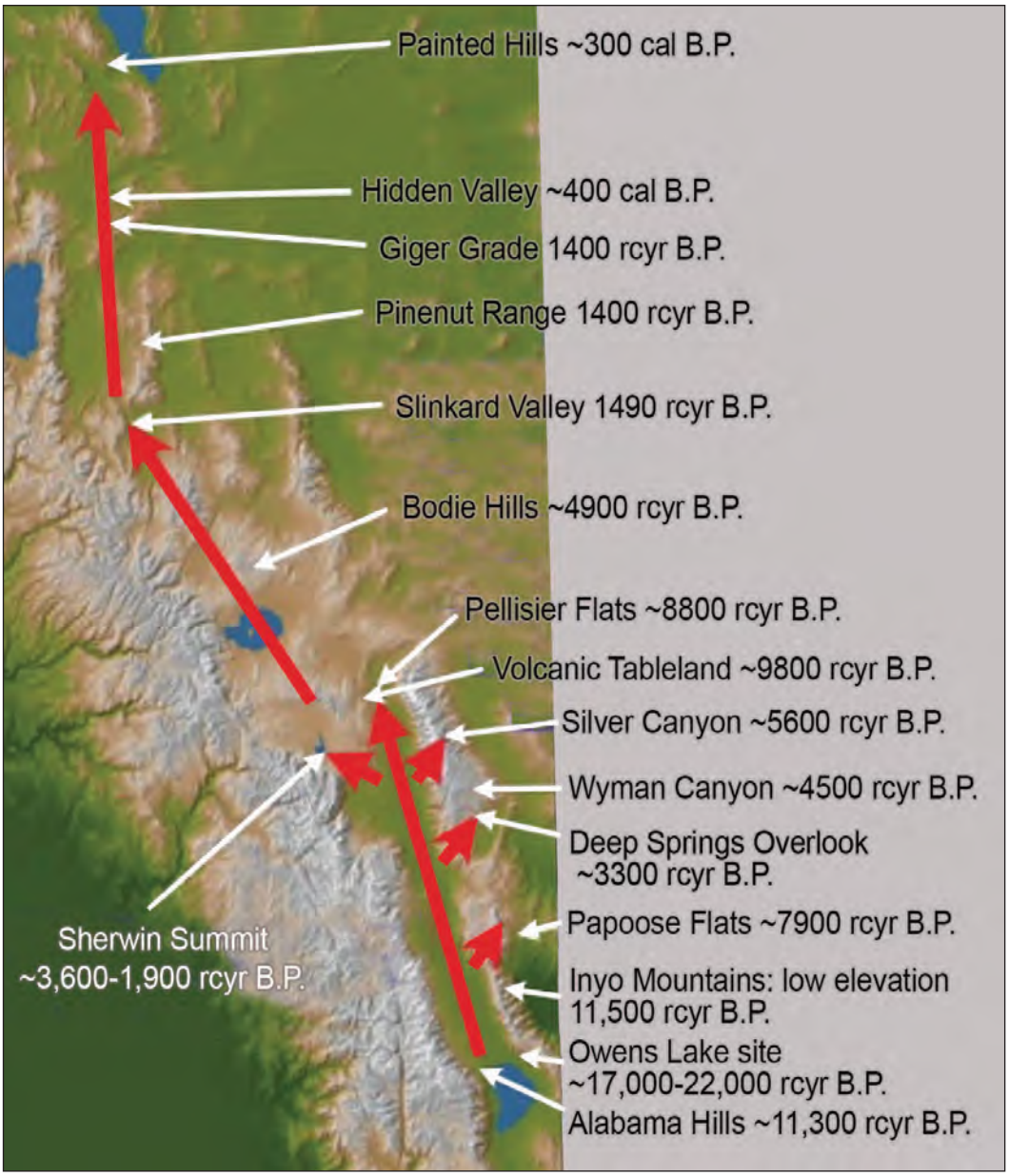

Figure 3-10—Northern movement of singleleaf pinyon along the east slopes of the Sierra Nevada range during the late Pleistocene and Holocene as a result of temperature changes. Note that evidence of the arrival of pinyon in this portion of the Great Basin does not show up until 4,900 years ago in the Bodie Hills near Mono Lake, and only arrives near Pyramid Lake 300 years ago (derived from Wigand 2017).

The northward expansion of singleleaf pine was considerably slower along the east slopes of the Sierras than the migration of singleleaf pinyon in eastern Nevada during this period, remaining south of the Utah and Colorado borders. Migration north along the Sierras was probably limited by variable climate conditions, particularly during dry cold periods. (Peter Wigand, Graduate Faculty, Department of Geography & Research Faculty, Graduate Program of Hydrological Sciences, University of Nevada, Reno, personal communication, 2019).

Vegetation: Late Holocene 5,000 Years Ago to 1850

The late Holocene was generally cooler and wetter than the mid Holocene, but there were several long-term cool and moist, warm and dry (table 3-3; fig. 3-1), and cool and dry periods, which caused vegetation movement (Cole et al. 2013; Grayson 2011; Nowak et al. 1994a,b). Woodlands reached their late Holocene presettlement maximum in expanse and abundance during the cool and wet Neoglacial period—2,000–4,000 years ago (Wigand et al. 1995; Wigand and Nowak 1992). Climate conditions during this period favored tree growth, cone production, and seedling establishment (Johnsen 1962; Fritts and Ziangdig 1986; Redmond et al. 2012; Smith et al. 1975). The shift toward increasing dominance of pinyon over juniper likely began during the end of the Neoglacial with warming temperatures. The Medieval Warm Period—A.D. 900 to A.D. 1300— (figs. 3-1, 3-9) followed the Neoglacial and included the 4 driest periods in the past 1,300 years (Cook et al. 2004). It resulted in a significant decline in areas occupied by pinyon and juniper during the Neoglacial (Davis 1982; Holmes et al. 1886; Stine 1990; Wigand 1987; Wigand and Nowak 1992; Wigand and Rose 1990).

However, both woodrat middens and the pollen record from Lead Lake in the Carson Sink indicate that pinyon pine increased markedly with respect to juniper during this period (Wigand and Rhode 2002). This corresponds with a drop in elevational distribution and northward latitudinal expansion of pinyon in woodrat middens of the area, suggesting the increase in summer precipitation may have been a more significant factor in the expansion of pinyon at that time. The combination of severe drought and increased fire, based on charcoal evidence, often occurred during these transition periods from wet to dry. The transition from cool and moist to warm and dry during the late Holocene coincided with dramatic reductions in juniper pollen in the north (Wigand 1987) and both juniper and pinyon pollen in the south (Wigand and Rose 1990).

The beginning of the Little Ice Age, around A.D. 1300, marks the onset of the re-expansion of pinyon and juniper woodlands and the continued shift toward the increasing proportion of pinyon over juniper (Gray et al. 2006; Wigand and Nowak 1992). But woodlands declined in the second half of the 1500s during a megadrought which influenced much of western North America (Emily Heyerdahl Dendrochronologist, USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana, personal communication, 2014; Swetnam and Betancourt 1998). Expansion and infill (see Glossary) of woodlands resumed following the megadrought and continued during the 1600s through the mid-1800s (Floyd et al. 2017; Miller et al. 2008; Soulé and Knapp 2000; Waichler et al. 2001; Emily Heyerdahl, Dendrochronologist, USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana, personal communication, 2016). In areas where pinyon and juniper grew in mixed stands, increases were greatest for pinyon during the past few centuries (Biondi and Bradley 2013; Despain and Mosley 1990; Wigand et al. 1995).

Both singleleaf and twoneedle pinyons continued to moved northward during the late Holocene, approaching their current northern distributions during the last hundred years. By the late Holocene, between 6,300–1,700 years ago, singleleaf pinyon approached its northern boundary in the central Great Basin along the Nevada and Utah border, but remained absent north of Mono Lake on the east slope of the Sierras and in central Nevada (figs. 3-5g, 3-10; Cole et al. 2013). The earliest evidence of singleleaf pinyon entering the western Great Basin was 4,900 years ago in Bodie Hills, just north of Mono Lake, California. Its continued progression north stalled until around 1,500 years ago (Nowak et al. 1994a), arriving at its present-day northwestern boundary near the southwest shores of Pyramid Lake about 300 years ago. Singleleaf pinyon finally appeared in central Nevada less than 2,000 years ago (Cole et al. 2013). Twoneedle pinyon moved northward into Utah, Colorado, and Wyoming between 6,300 and 1,700

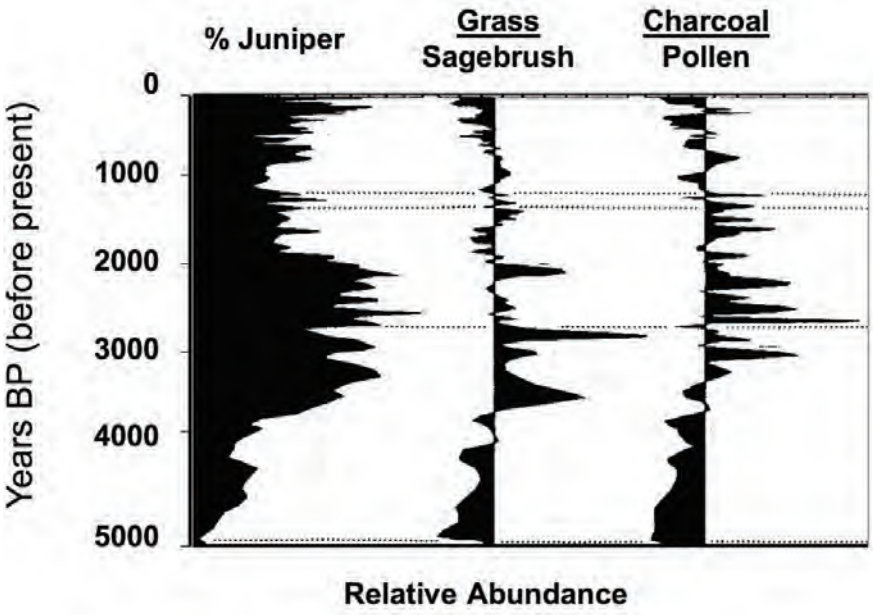

Figure 3-11—Measurements from sediment cores collected at Diamond Craters in southeastern Oregon include juniper pollen percentages, ratios of grass to sagebrush pollen, and ratios of juniper pollen to charcoal. Shifts to the right represent increasing relative abundance of juniper, grass pollen in relation to sagebrush pollen, and charcoal in relation to juniper pollen brought about by increased incidence/frequency of fire (Mehringer and Wigand 1990).

years ago (Cole et al. 2013). It arrived at its current northern boundary in the Dutch John Mountains of northeastern Utah near the Wyoming border about 500 years ago (Gray et al. 2006). Its movement northward stalled during the Medieval Warm Period around A.D. 1250 but rapidly resumed during the Little Ice Age. The current northern geographic boundaries of both singleleaf and twoneedle pinyons are thought to be related to late winter and early spring temperatures (Nowak et al. 1994a; West et al. 1978). Rapid temperature fluctuations during late winter and early spring in this region can cause dormancy to break early in pinyon, making them susceptible to frost damage.

Western juniper first arrived in its current geographic range in central and southeastern Oregon (Bedwell 1973; Wigand 1987) and northeastern California (Mehringer and Wigand 1984) during the mid Holocene, between 4,800–6,600 years ago. It rapidly expanded during the cool and moist Neoglacial period between 4,000–3,000 years ago, reaching its prehistoric maximum and extending across most of its present-day range (fig. 3-11; Mehringer and Wigand 1990; Wigand et al. 1995). However, severe droughts and major fires during the transition between the post-Neoglacial and Medieval Warm periods 2,500–2,000 years ago resulted in significant regional declines in western juniper (Mehringer and Wigand 1990; Wigand et al. 1995). As conditions cooled and moisture increased entering into the Little Ice Age, western juniper began to gradually increase based on pollen records (Mehringer and Wigand 1990).

Recent Historic Patterns

Late Presettlement Woodland Expansion and Infill

> *"In the past 150 to 300 years, expansion of juniper and pinyon from their original distribution and densities has presented problems in classifying present vegetation in relation to the historic climax plant community, and in correlating this plant community to specific environmental factors" (Vasek and Thorne 1977).*

Climate conditions in the Great Basin and Colorado Plateau during the middle of the last millennium were generally cooler and wetter than currently (fig. 3-9) with the thermal minimum occurring around A.D. 1700 (Eddy and Bradley 1991; Lowell 2000). However, drought persisted in much of the northwestern Great Basin until the last phase of the Little Ice Age, which began about 300 years ago. Following the end of the Little Ice Age, temperatures warmed, but conditions stayed relatively moist with a persistent wet period between 1905 and 1917 across the West (Woodhouse et al. 2005). After 1920, climate in the Great Basin and Colorado Plateau became generally warmer (Eddy and Bradley 1991; Ghil and Vautgard 1991; Woolfenden 1996) and drier (Cook et al. 2004) and was marked by severe droughts. In the Great Basin one of the most severe droughts began in the 1920s, peaking in the 1930s (fig. 3-12a; Miller et al. 2011). However, in the Colorado Plateau this drought was not as severe (fig. 3-12b). Droughts again occurred across both regions in the 1950s, late 1980s, and early 2000s, resulting in considerably greater tree mortality in the Colorado Plateau than the Great Basin (Biondi and Bradley 2013; Breshears et al. 2005; Shaw et al. 2005).

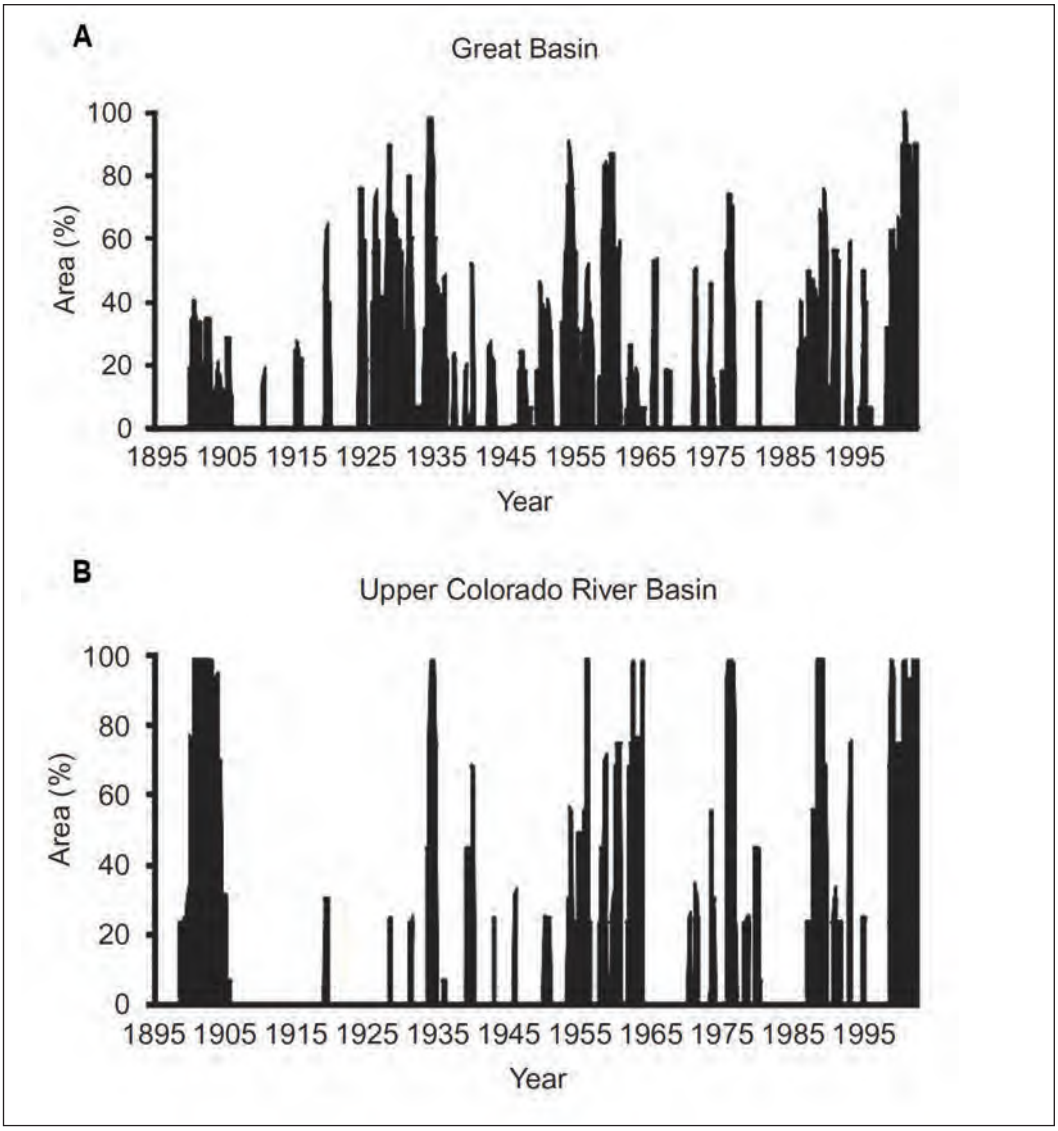

Figure 3-12—Percent area of major river basins in the (A) Great Basin and (B) Upper Colorado River Basin experiencing drought conditions from 1895–2004. Note the wet periods in the early 1900s for both regions. Graphs depict the Palmer Drought Severity Index (1965), a measure of the extent of departure from long-term average precipitation, temperature, and available water capacity (Miller et al. 2011).

Figure 3-13—Remnant wood in old growth stands can persist for centuries, providing clues to past woodland stand structure and climate. Horse Ridge, central Oregon. (Photo by Rick Miller, Oregon State University.)

Between the mid-1800s to the mid-1900s, packrat middens, pinyon and juniper pollen, and tree-ring chronologies strongly suggest an unprecedented increase in the rate of expansion and infill (increased density) of pinyon and juniper woodlands (table 3-4) (Biondi and Bradley 2013; Cole et al. 1997; Landis and Bailey 2005; Mehringer and Wigand 1990; Miller and Wigand 1994b). Questions addressed in this section include:

1) What were the structure and composition of mature woodlands prior to Eurasian settlement?
2) Were the distribution and density of pinyon and juniper woodlands stable just prior to Eurasian settlement?
3) What is the magnitude of expansion into sagebrush and associated plant communities?
4) Are there regional differences in woodland dynamics and disturbance regimes?
5) What were the contributing factors to woodland expansion and infill across the Intermountain West during the late 19th and 20th centuries?

Presettlement Woodlands Just Prior to Settlement

Evidence of change in woodland structure, infill, and expansion since the 1850s comes largely from tree-ring chronologies, remnant wood, sediment cores, charcoal, fire-scars, soil characteristics, and early observations (fig. 3-13). Most historical photos were taken several decades following postsettlement tree harvest of thousands of acres during the Comstock period between 1863 and 1908 across Nevada and Utah, and they must be interpreted carefully (Creque et al. 1999). Distant, casual observations of woodland structure must also be interpreted cautiously as illustrated by Woodbury (1947). He said that, “From a distance, the forest (pinyon and juniper woodland) appears to be a solid dark belt, but upon closer inspection, it is found that the stand is open with much space between the trees.”

Table 3-4—Tree chronology studies across Great Basin and Colorado Plateau. Infill (I) occurs where old trees (mature prior to 1850) were present and expansion (E) where there was no evidence of old trees having been present on the site. Post-1950 trend in tree establishment compared to the first half of the 20th century.

Reference	Location	Period of chronology	Expansion (E) or Infill (I)	Tree species	Plant community	Peak establishment	Post-1950 trend	Comments
Adams 1975+A2:J21	central OR	1890–1970	NA	JUOC	ARTRv-PUTR	1920–1930	Decline	Postsettlement woodland of which 71 percent of the trees established between 1900 and 1935; increase started 1900
Barger & others 2009	Grand Staircase SC UT	1440–1940	I	PIED JUOS	Shallow sandy loams; ppt 14"	1910–1940 (1920–1929)	Na	Little evidence of fire; no difference in tree density between grazed and nongrazed although tree basal area was greater in grazed; herbaceous understory cover was 5–6 percent, not adequate to support a surface fire
Biondi & Bradley 2013	Mt Irish SE NV	1400–2000	I	PIMO	Upper moisture end of pinyon	1900–1940 1930–1960	Decline	Mt Irish: PIMO dominant tree more than doubled since 1800; mortality less than 10 percent; primarily infill; Mt Clover: PIMO more than doubled since 1800; mortality less than 10 percent; primarily infill; tree establishment primarily PIMO
	Clover Mts SE NV	1400–2000	I	PIMO	Upper moisture end of pinyon	1880–1930	Decline	
Blackburn & Tueller 1970	4 locations south of Ely, NV	1700–1970	E?	PIMO-JUOS	ARNO/PSSP	1920	Decline	No presettlement trees present; did not measure large dead wood; site south of Ely, likely harvested in the late 1800s and is regenerating
		1700–1970	I	PIMO	ARNO/PSSP	1920	Decline	Low density of old trees may indicate this site was not harvested in the late 1800s
Bolsinger 1989	NE CA	< 1780–1980	E & I	JUOC	Mixed	1880–1930		73 percent of woodlands < 100 yr old; trees in 50-yr age classes
	E CA	< 1780–1980	E & I	JUOS PIMO	Mixed	1880–1930		59 percent of woodlands <100 yr old; trees in 50-yr age classes
Burkhardt & Tisdale 1976	SW ID	1870–1970	E & I	JUOC	ARTRv/ FEID-PSSP & ARAR	1920–1940	Decline	JUOC actively invading mountain big sagebrush; mature stands primarily ridges and rim rocks
Despain & Mosely 1990	AZ near Flagstaff		I	PIED JUOS	Elevation 6,700 ft; ppt 18" adjacent to PIPO	1880–1920 on > 50 percent plots	Decline	10 locations across 740 acres; 20 to 40 trees cored in each macro plot. Estimated age structure from diameters, which relationships were generally weak. Stand structure and lack of dead and downed wood suggest tree density has increased significantly within the past 200 yrs.
Eisenhart 2004	Uncompahgre Plateau W CO	1300–2000	E & I	PIED JUOS	Mixed	1880–1920	Decline	4 locations across the Colorado Plateau; shows fairly steady expansion based on stand age between 1500 to 1950; peaking around 1900 on 4 of the 3 sites. Rapid tree ring growth around 1910–1920.
Floyd-Hanna et al. 2004	Mesa Verde SW CO	1600–2000	I	PIED	Mixed	1910–1940	Decline	CP had longer wet period in first half of 1900s than the n GB; all stands showed an increase from 1900-1940.

(Continued)

Table 3-4—(Continued).

Reference	Location	Period of chronology	Expansion (E) or Infill (I)	Tree species	Plant community	Peak establishment	Post-1950 trend	Comments
Floyd-Hanna et al. 2008	N AZ	na	I	PIED JUOS	ARTR-PUTR hot-dry; ppt 12"	early 1900s	Na	Measured age of stands by sampling oldest trees; most stands had a large cohort of trees establishing in the early 1900s
Hattori et al.	W & C NV	NA	NA	PIMO JUOS	Mixed	NA	N	Chronology for depicting timing of cut during late 1800s mining. Upper elevation woodlands composed of larger but less dense canopies then lower reestablished (cutting for charcoal) dense younger woodlands below.
Heyerdahl et al.; unpublished data Horse Ridge	C OR Horse Ridge	800–2000	I	JUOC	ARTRv, ARTRw, PSSP	1600–1800		Relatively stable old-growth woodland; pulse occurs around 1700
Johnson & Miller 2008	SW ID	< 1850	E & I	JUOC	mixed	1900–1920	Decline	OR > 9-fold increase; ID > 2-fold
Landis & Bailey 2005	AZ Mogollon Rim	1400–2000	I	PIED JUOS	Basalt	1880–1960	No	Tree establishment declined around 1950 on sandstone derived soils but not occurring on basalt or limestone derived soils. Canopy cover in 1860 and 2002 was 4.5 and 30 percent (670 percent increase) on basalt, 11.5 and 33.8 percent (300 percent increase) on limestone, and 14.7 and 44.3 percent (300 percent increase) on sandstone. Since the 1950s drought, recruitment on limestone and sandstone dominated by JUOS and on basalt PIED.
			I		Sandstone	1880–1920	Decline	
			I		Limestone 6,300–6,800 ft	1860–1960	No	
Margolis 2014	NC NM			PIED JUMO JUSC	BOGR savanna 6,400–8,000 ft	1900–1930	Decline	Tree density has increased 600 percent since the late 1800s.
	UT	1600–2000	E & I	PIMO JUOS		1940–1970	Decline	Transects from the lower to upper woodland boundary covering Artrw, Artrv, and Arar; 9-fold increase since 1900
	NV	1800–2000	E & I	PIMO, JUOS		1920–1950	Decline	
	ID	1800–2000	E & I	JUOC		1920	Decline	5–10 percent cover; 5–11 trees/ac
Miller et al. 2008	OR	1800–2000	E & I	JUOC		NA	Decline	Study showed substantial infill and expansion across the Great Basin

(Continued)

Table 3-4—(Continued).

Reference	Location	Period of chronology	Expansion (E) or Infill (I)	Tree species	Plant community	Peak establishment	Post-1950 trend	Comments
Miller & Heyerdahl 2008		1750–2000	I	JUOC	ACOC	1880–1900	Decline	Infill: about double; pulse not consistent across communities e.g., sage-fescue or sage bluebunch
		1870–2000	E		ARTRv/PSSP	NA	Decline	Last fire across sagebrush sites in 1941, no evidence of old charred trees
	NE CA	1880–2000	E	JUOC	ARTRv/FEID	NA	Decline	Frequent fire regime
Miller & Rose 1995	Steens	1700–1990		JUOC	ARTRv, ARAR	NA	Decline	expansion into ARTRv; scattered old trees present on ARAR; few on south aspects; none on north slopes or POTR
			E	JUOC	ARTRv/FEID	1900-1920	Decline	
Miller & Rose 1999	C OR	1840–1995	I	JUOC	ARAR & south	1900–1920	Decline	OG very open ARAR sites; trees > 2-fold increase; ARAR old trees only accounted for 1.5 percent with a canopy of < 5 percent; OG very scarce in ARTRv plots
Miller unpublished data	Horse Ridge E OR	1587–1997	I	JUOC	ARTRv, FEID	1700	No	Very minimal anthropogenic disturbance
Soule & Knapp 2000	I land INRA E OR	1827–1997	yes	JUOC	ARTRv, PSSP	1978–1996	No	Old relict stand (island) with minimal disturbance
Tausch et al. 1981	NV	1400–1980	reestablish	PIMO JUOS		1905–1930	Decline	48 percent of the juniper and 71 percent of the pinyon plots were dominated by trees < 150 yrs old; really a study of expansion based on fig 5 not number of trees establishing.
Tausch & West 1988	SW UT	1835–1976	N/A	PIMO, JUOS		1920–1945	Decline	Reestablishment following mid-1800s fire was primarily pinyon but 38 percent juniper postfire survival and only 0.6 percent pinyon; decline after 1945 but surge in 1975 (based on seedling count)
Wall et al. 2001	E OR, NE CA, NW NV	1880–1990	E	JUOC	Aspen	1910–1919	Decline	Chronology dates back to oldest tree measured
Young & Evans 1981	NE CA	1850–1960	I	JUOC	Big sagebrush	1880–1920	Decline	Few scattered old trees present
		1600–1960	I	JUOC	Low sagebrush	1750 & 1880–1915	Decline	Peaks 1650–1750; 1850–1900
Waichler et al. 2001	C OR	1300–1990	I	JUOC	ARTRv, ARTRw, PSSP	1700–1850	Decline	Chronology for stable old-growth stand about 20 percet trees < 150 yrs; 11–33 percent tree cover and 30 trees/ac; infill very slow

ACOC = western needlegrass, ARAR = low sagebrush, ARNO = black sagebrush, ARTRv = mountain big sagebrush, ARTRw = Wyoming big sagebrush, FEID = Idaho fescue, JUOC = western juniper, JUOS = Utah juniper, PIED = twoneedle pinyon, PIMO = singleleaf pinyon, PSSP = bluebunch wheatgrass, PUTR = bitterbrush.

Early observations can often appear contradictory but seem to reflect the heterogeneity of pinyon and juniper woodlands in the Great Basin and Colorado Plateau at the time of settlement. When John Muir traveled across 11 mountain ranges in Nevada in 1878, he wrote about pinyon:

> *"In the number of individual trees and extent of range this curious little conifer surpasses all the others combined. Nearly every mountain in the state is planted with it, from near the base to a height of from eight thousand to nine thousand feet above the sea. Some are covered from base to summit by this one species, with only a sparse growth of juniper on the lower slopes to break the continuity of these curious woods. ... Tens of thousands of acres occur in one continuous belt. Indeed, the entire state seems to be pretty evenly divided into mountain ranges covered with nut pines and plains covered with sage—now a swath of pines stretching from north to south, now a swath of sage; the one black, the other gray; one severely level, the other sweeping on complacently over ridge and valley and lofty crowning dome." (From early writings of John Muir, reprinted in* Steep Trails, *1994.)*

However, reports by John C. Fremont in 1842 and Parley P. Pratt in 1851 described vegetation in the Mountain Meadows of southwestern Utah very differently. Their separate accounts summarized by Cottam and Stewart (1940) provided a very different picture.

> *"The entire valley as seen by Fremont in 1842 and Pratt 1851 was grass-covered. ... Pratt stated the surrounding hills were abrupt, but rounded off, presenting a variety of beauteous landscapes and everywhere richly clothed with the choicest kind of bunch-grass, and bordered in their higher eminences with cedar and nut pine sufficient for fuel."*

In the same valley, Cottam and Stewart conducted an extensive study in 1930 and reported:

> *"For a number of years young junipers in great numbers have been appearing in areas hitherto unoccupied by them"* (Cottam and Stewart 1940).

In the Crooked River Canyon, upriver from Prineville, Oregon, Peter Skene Odgen wrote in his journal in 1825 that *"as we headed up the Crooked River we saw the occasional cedar tree up on the rimrock."*

Today the river canyon is densely populated with western juniper (fig. 3-14;, Rick Miller Professor emeritus Range Ecology, Oregon State University, Corvallis, Oregon, personal observation, 2016). In 1901, Griffith (1902) observed only scattered stands of juniper on Steens Mountain in southeastern Oregon where little cutting had occurred. And in Arizona, Leopold (1924) observed young trees encroaching on grassland parks after the introduction of livestock.

Structure of Persistent Woodlands Prior to Settlement

The 1850s marked the end of the Little Ice Age and the early 1860s a significant rise in modern anthropogenic impacts—including the introduction of large numbers of livestock throughout the Intermountain West (fig. 3-9). In the literature, this period is frequently used to separate presettlement and postsettlement pinyon and juniper woodlands. Tree-age ratios and the presence and densities of snags, remnant logs, and stumps in old-growth woodlands strongly suggest tree densities were lower prior to 1850 than today (table 3-4; figs. 3-15, 3-16). Studies indicate tree densities in old-growth woodlands increased two- to ninefold since 1860, which exceeds expected compensation for natural mortality (Baisan and Swetnam 1990; Barger et al. 2009; Biondi et al. 2013; Floyd et al. 2017; Floyd-Hanna et al. 2004; Hattori and Thompson 1987; Landis and Bailey 2005; Miller et al. 2008; Miller and Rose 1999, 2005; Waichler et al. 2001).

The large difference between low mortality of mature trees and rapid tree establishment since 1850 has resulted in significant infill in many old-growth (persistent)

Figure 3-14—Peter Skene Ogden observed only scattered "cedar trees" up on the rimrock as he traveled along the Crooked River in the 1820s. Crooked River Canyon, central Oregon. (Photo by Rick Miller, Oregon State University.)

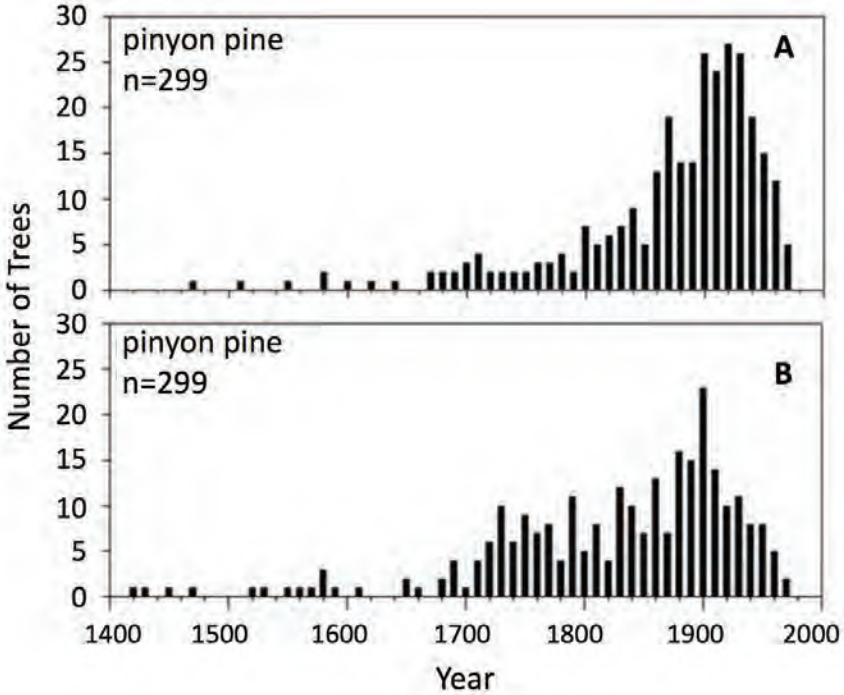

Figure 3-15—Age structure of pinyon pine sampled across (A) Mount Irish (B) and Clover Mountain in Nevada. Both study areas represent persistent woodlands and illustrate the pulse of tree establishment (infill) during the early 1900s (Biondi and Bradley 2013).

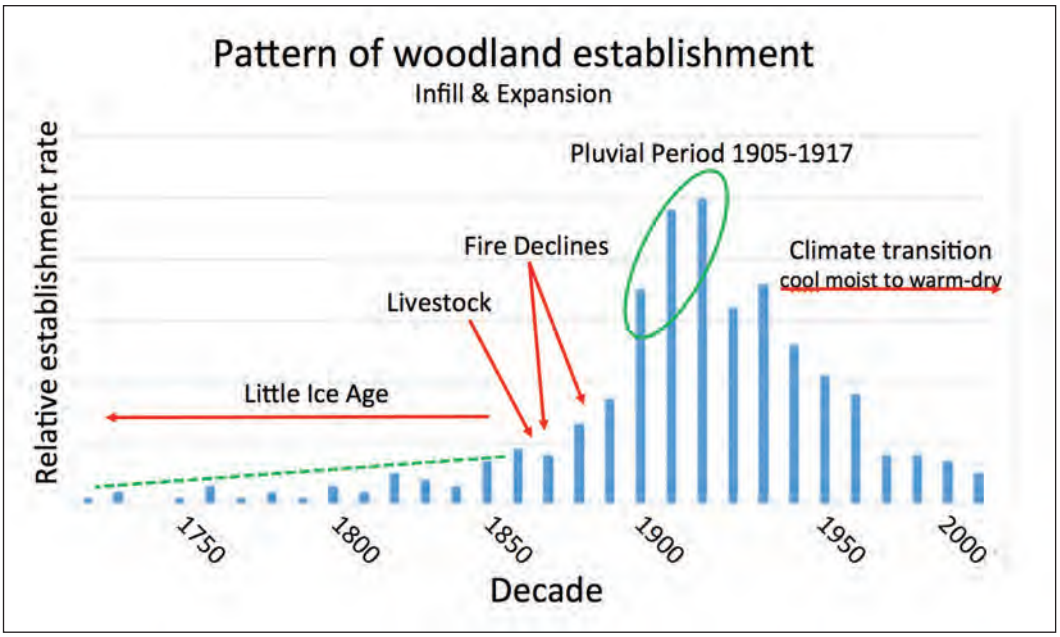

Figure 3-16—Decadal establishment of pinyon and juniper, which represents the general pattern shown by many pinyon-juniper chronologies conducted throughout the Great Basin and Colorado Plateau since the late 1800s.

woodlands across the Intermountain Region. Densities of dead trees, stumps, and logs, which can persist for centuries, suggest natural mortality of mature trees in largely undisturbed (in the absence of episodic events) old-growth woodlands is very low, less than 1 percent per century (Landis and Bailey 2005; Waichler et al. 2001). In relatively undisturbed old-growth woodlands in central Oregon, trees less than 150 years old made up 22 percent of the total population (85 trees per acre), well exceeding mortality rates that were less than 1 percent over multiple centuries (fig. 3-13; Waichler et al. 2001). The more open pre-1850s woodlands across the Great Basin and Colorado Plateau were often characterized by understory vegetation of shrubs, grasses, and forbs, frequently mentioned in paleobotany literature. However, there are persistent woodlands that have experienced heavy mortality from past periods of severe drought and insect infestation, especially the Colorado Plateau, and infrequent fires resulting in persistent woodlands exhibiting less old-growth characteristics. Also, considering the large spatial heterogeneity in climate, soils, and topography across the Great Basin and Colorado Plateau, closed stands with little understory cover, such as those observed by Muir in 1878 and Phillips (1909) at the turn of the century, also existed.

Based on estimated presettlement tree densities from tree core evidence, tree canopy cover was relatively open throughout many pinyon and juniper woodlands throughout the Great Basin and Colorado Plateau. In Arizona and Utah, presettlement tree canopy cover across three separate old-growth woodlands was estimated at 4.5–14.7 percent in 1860 (Landis and Bailey 2005). Before 1860 in the northwestern Great Basin, tree canopy cover across an extensive old-growth woodland varied from less than 5–33 percent (Waichler et al. 2001). These open stands likely supported high understory cover where climate and soils were suitable. Pollen and packrat midden evidence also suggests woodlands with well-developed sagebrush and grass understories (Anderson et al. 2000; Spaulding 1990; Wigand et al. 1994a,b; Woolfenden 1996).

Environmental factors that limited stand closure of presettlement woodlands are unknown. There is limited evidence that reoccurring low-intensity surface fires

maintained the open structure of presettlement woodlands (Baker and Shinneman 2004; Romme et al. 2009; Waichler et al. 2001). But low-severity fires were reported as common in pinyon and juniper woodlands of east Texas, influencing tree densities (Poulos et al. 2009). In the central Great Basin, frequent low-severity fires were also attributed to relatively lower density tree canopies, but in the upper elevation belt where pinyon was intermingling with mixed conifer (Biondi et al. 2011). On a nearby mountain range, the fire regime was characterized by infrequent fires with occasional patchy high-severity events. In the absence of reoccurring low-intensity fires, openness of pinyon and juniper woodlands, frequently reported in the paleobotany literature, would have had to be the result of limited tree-seedling establishment and/or natural thinning processes, especially of young trees. Establishment of tree seedlings resulting in infill and thickening of presettlement woodlands may have been limited or slowed down by competition from herbaceous vegetation (Guenther et al. 2004; Madany and West 1983; Soulé et al. 2004). Thinning may have also been caused by droughts and pests (Eisenhart 2004; Floyd et al. 2009; Greenwood and Weisberg 2008; Koepke and Kolb 2013; Koepke et al. 2010). We have little information as to how Native Americans may have managed woodland structure prior to Eurasian settlement.

Presettlement Fire Regimes

Persistent woodlands occur where disturbance regimes, soils, and climate are inherently favorable for pinyon and/or juniper (Romme et al. 2009) from establishment through maturation to late succession. Persistent woodlands exhibiting old-growth characteristics occur across a wide range of soils and parent materials but develop where stand-replacement disturbances are rare, extending over centuries (Harper and Davis 1999; Leonard et al. 1987; Pearson 1931; Springfield 1976; Stringham et al. 2015; West et al. 1998). Old-growth woodlands or trees are most often found on rock outcrops, knolls, and ridges with soils that are shallow, coarse, rocky, and often high in clay or sand (Barney and Frischknecht 1974; Bauer and Weisberg 2009; Cottam and Stewart 1940; Holmes et al. 1986; Miller and Rose 1999; Nicol 1937; Stringham et al. 2015; Woodbury 1947). These soils are often nutrient limited and support sparse and discontinuous fine surface fuels, resulting in fire return intervals measured in centuries (Barger et al. 2009; Floyd et al. 2004; Waichler et al. 2001). However, on more productive sites with moderately deep to deep soils, where cool and moist sagebrush communities were persistent, fire has been an important disturbance limiting expansion of pinyon and juniper. In general, fires typically increased (as evidenced by charcoal abundance and size) during extended wetter periods punctuated by droughts and declined during extended periods of drier climate (Wigand 2017).

Fire regimes characterize the nature of fire for a specific area over an extended period of time. Characteristics of fire regimes include frequency of occurrence, severity, intensity, size, complexity, and season for a specific area or plant community. Fire frequency, often reported as fire return interval, is an important factor determining the dynamics and persistence of plant communities. Fire return interval is sometimes confused with fire rotation. Fire rotation is the time required for a cumulative area burned to equal the size of the defined area of interest (Sugihara et al 2006). Fire rotation does not account for the heterogeneity of fire in time and space across a landscape or at local scales (Agee 1993; Heinselman 1973; Reed 2006). But the term is useful in describing fires in relatively homogenous vegetation and at regional scales when it is not realistic to evaluate landscapes at fine scales as a result of limited data. Fire return interval is the length of time between fires for a specific area. Mean fire return interval is most commonly reported in the literature. It represents the arithmetic average of all fire intervals over a designated period for a specific site or defined area. However, variation

in fire return intervals is a more important determining factor influencing long-term vegetation dynamics and persistence.

"Means are abstract values that we often falsely interpret as a concrete thing. Variability is the universal reality" (Gould 1997).

The variation of fire return intervals in both time and space can describe the fine-scale complexity of fire across landscapes. The heterogeneity of fire occurrences at finer scales across landscapes have important ecological consequences related to processes, functions, and habitat configurations within landscapes (Miller et al. 2011). However, a primary limitation of calculating fire return intervals across semiarid communities is often the scarcity of fire scar data. In plant communities where trees persist or have recently expanded, tree-age structure analysis can supplement fire scar data as a proxy for estimating fire return intervals, especially where fires are stand replacing (Agee 1993).

Historic fire regimes were highly heterogeneous at local and regional scales in the Great Basin and Colorado Plateau due to variation in ignition, fuel, climate, topography, and vegetation (fig. 3-17; Marlon et al. 2012; Miller et al. 2011). Recent fire records across this region show that distinct regional patterns in present-day fire occurrences are largely determined by climate (fig. 3-18; Board et al. 2018; Littell et al. 2009), especially as climate affects ignitions, fuel characteristics, and timing and amounts of precipitation. Fires are significantly more common in the northern Intermountain Region and along the Wasatch Mountains and Mogollon Rim than the southern Great Basin and Colorado Plateau. While abundance and distribution of invasive annual grasses are likely influencing present-day regional fire occurrences in the northwestern Great Basin, Columbia Basin, and Snake River Basin, they do not represent the only reason for increased fire frequency in these regions. Seasonal patterns of lightning ignition in the northwestern Great Basin coincide with the season of peak surface fuel abundance and low fuel moisture content (West 1983).

Figure 3-17—Topography can be linked to very patchy fires, especially when burning under less severe weather conditions. Fairview Range, Nevada. (Photo by Rick Miller, Oregon State University.)

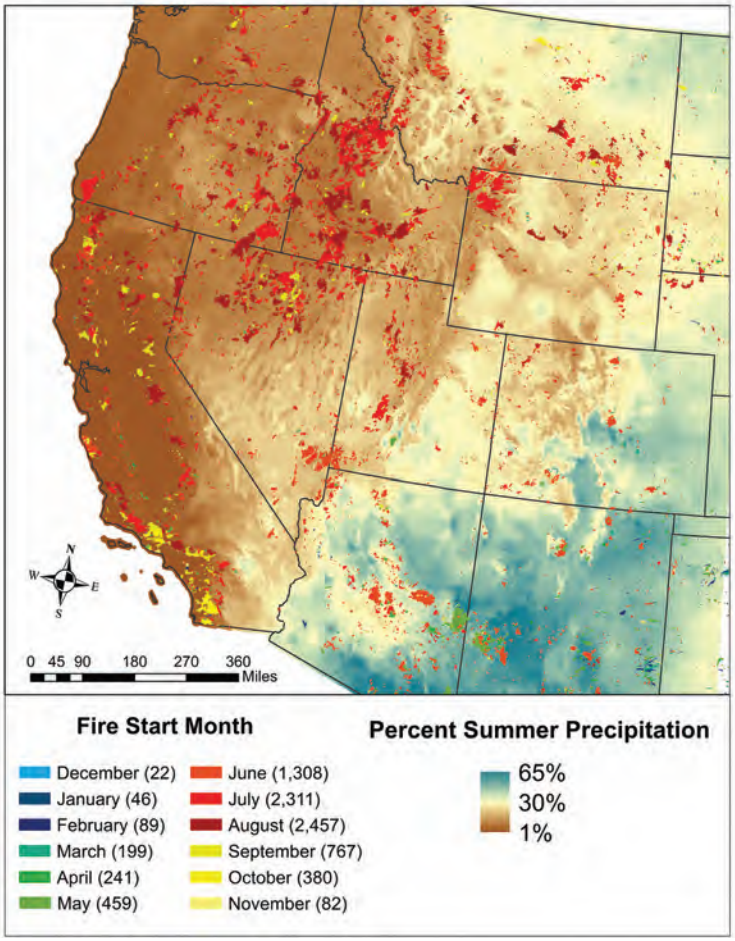

Figure 3-18—Large western fire events (more than 1,000 acres) between 2000–2014. Depicted are fire event timing (month of start) and percentage of summer precipitation (derived by David Board).

Fire regimes can also vary abruptly among adjacent sites, as soils or aspects change, resulting in complex spatial patterns in fire return intervals. In the northwestern Great Basin, historic mean fire return intervals ranged from 10 to over 100 years across different plant communities occupying different aspects and soils (Miller and Heyerdahl 2008). Relatively short fire return intervals (less than 15 years) were reported on the more productive soils and northerly aspects where fire intervals were relatively short, fine surface fuels were 2,000–2,400 pounds per acre, and cover was 30–45 percent (predominately Idaho fescue and bluebunch wheatgrass grassland with less than 3 percent ponderosa pine cover and a few old junipers growing on rock protected microsites). In an immediately adjacent plant community (western juniper-western needlegrass) with little to no aspect and coarse-low productive soils, fine surface fuel loads were 100 pounds per acre with less than 10 percent cover. Fire return intervals here were more than 100 years. On the Colorado Plateau, mosaics of big sagebrush were typically found on the deeper soils (fig. 2-38) immediately adjacent to old-growth pinyon and juniper woodlands, which often occupied the shallow soils (fig. 2-7; Floyd et al. 2008). The combination of fuels and competition on these deeper soil sites may have limited the conversion to persistent woodlands.

Presettlement Fire Regimes: Pinyon and Juniper Woodlands

Fire return intervals are long, often centuries long, in persistent pinyon and juniper woodlands (Baker and Shinneman 2004; Barger et al. 2009; Board et al. 2018; Floyd et al. 2000, 2004, 2017; Huffman et al. 2008; Waichler et al. 2001). This allows woodlands to reach late successional stage and develop old-growth structural characteristics. Fire regimes in persistent or old-growth woodlands have changed little in the past several

centuries. But there appears to be an increasing trend of stand-replacement fires in persistent woodlands over the last 30 years (fig. 3-19; Barger et al. 2009; Board et al. 2018; Floyd et al. 2000, 2004, 2017; Waichler et al. 2001). Sparse surface fuels are likely the reason for infrequent fire. Fire spread in closed-canopy woodlands lacking an understory requires severe weather conditions and often results in stand-replacement events (Blackburn and Bruner 1975; Schroeder 1966). Low-severity fires in persistent woodlands are rare (Baker and Shinneman 2004; Romme et al. 2009; Waichler et al. 2001). Limited surface fuels in persistent woodlands are often a function of low productivity and shallow, very coarse-textured soils (Leonard et al. 1987; Stringham et al. 2015; USDA NRCS Harney County, Soil Survey of Harney County Area, Oregon 1997; Randy Lewis, Soil Scientist, USDA NRCS, Tremonton, Utah, personal communication, 2015). On more productive sites, competition from trees also limits understory productivity (Roundy et al. 2014a). Minimum surface fuels sufficiently able to carry fire under moderate weather conditions are estimated at 740 pounds per acre (Bunting et al. 1987; Evers et al. 2013; Gruell et al. 1986).

We have little information as to the role of fire in open persistent woodlands with abundant understory vegetation (Romme et al. 2009). Although there is limited evidence that fire thinned some persistent open woodlands (fig. 3-20; Miller and Rose 1999), there is little evidence of reoccurring fires in the majority of these open old-growth stands (Robin Tausch, Retired Range Scientist, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada; and Rick Miller, Professor Emeritus, Range Ecology, Oregon State University, Corvallis, Oregon, personal observations, 2017). And many of these once open stands have exhibited significant recent infill, especially during the first half of the 20th century.

Figure 3-19—Fire return intervals in old-growth woodlands can typically be measured in centuries. However, in the past 30 years, there has been a significant increase in stand replacement fires—such as in Mesa Verde where a large portion of the monument's woodlands have burned since the 1990s. Mesa Verde 2000 Pony Fire, Colorado. (Photo by Rick Miller, Oregon State University.)

Figure 3-20—Presettlement woodlands were often considered relatively open, based on midden data and age structure of live and dead trees. There is little evidence of reoccurring low intensity fires that maintained this open structure. With limited mortality of mature trees, successful establishment of trees resulting in infill was likely very low. Horse Ridge, central Oregon. (Photo by Rick Miller, Oregon State University.)

In the northern Great Basin, low sagebrush-Sandberg bluegrass communities (which occur on shallow, heavy clay soils) support only low levels of fine surface fuels, resulting in infrequent fires. However, in eastern Oregon, following 2 or more wet years (Holmes et al. 1986), mixed severity fires in 1717 and 1855 resulted in nearly 100 percent mortality of small trees and around 25 percent mortality of old mature trees (Miller and Rose 1999). Many semiarid communities are fuel limited, thus the accumulation of fine fuel during wet years increases fuel continuity at the landscape level and has been closely linked to large and widespread fires (Abatzoglou and Kolden 2013; Allen et al. 1995; Baisan and Swetnam 1997; Brown et al. 2008; Grissino-Mayer and Swetnam 2000; Miller and Rose 1999; Swetnam and Betancourt 1998).

Presettlement Fire Regimes: Associated Sagebrush Communities

In sagebrush and grassland ecosystems for which environmental conditions were suitable for tree establishment and growth—but trees were absent—woodland expansion was likely limited or slowed by fire and competition from perennial grasses in presettlement times (Wright et al. 1979; see the competition and grazing subsections). Fire return intervals in sagebrush and grassland communities—especially on cool and moist sites with moderately deep soils—contained more contiguous surface fuels, resulting in shorter fire return intervals than most persistent woodlands (Bauer and Weisberg 2009; Miller and Heyerdahl 2008). But fire return intervals from 10 to more than 100 years varied in time and space across heterogeneous landscapes that supported different sagebrush and grassland communities (Lesica et al. 2007; Mensing et al. 2006; Miller and Heyerdahl 2008; Miller and Rose 1999; Wright and Bailey 1982). Within a landscape or watershed, historical fire return intervals often varied at relatively fine scales, from tens to hundreds to thousands of acres (Heyerdahl et al. 2006; Miller and Heyerdahl 2008).

Data on fire return intervals is very limited for the warm, dry sagebrush and semi-desert communities (for example, in Wyoming, big sagebrush and black sagebrush with less than 12 inches precipitation) at the lower elevation woodland boundary. Fires were likely infrequent, occurring only every hundred years or more (Mensing et al. 2006; Wright and Bailey 1982) with a high degree of variation around the mean return interval (Miller et al. 2001b). Low abundance and continuity of fine surface fuels limited fire occurrences and spread. In addition to occasional fires, environmental constraints—including drought, cold-air inversions in the spring during budding, pests, and competition from perennial grasses—limited woodland expansion in the lower elevation warm and dry shrublands. Moisture and temperature conditions in the warm and dry sagebrush and semi-desert communities would have been especially harsh on seedling establishment and young tree survival.

Mountain big sagebrush communities characterized by cool and moist conditions (12–16 inches precipitation) on moderately deep to deep mollic soils are much more likely to burn than drier sagebrush communities (e.g., Wyoming big, low, and black sagebrush), supporting significantly greater fine surface fuels (Heyerdahl et al. 2006; Lesica et al. 2007; Miller and Heyerdahl 2008; Miller and Rose 1999). Mountain big sagebrush communities, which often intermingle with and occur at the mid and upper elevation boundary of pinyon and juniper woodlands, were considerably more extensive prior to 1850 than they are today (Miller et al. 2008; Tausch and Nowak 1999). Along the ecotone between mountain big sagebrush and ponderosa pine or Douglas-fir communities, fire return intervals were relatively short, ranging from 10 to 30 years (Biondi and Bradley 2013; Heyerdahl et al. 2006; Lesica et al. 2007; Miller and Heyerdahl 2008; Miller and Rose 1999).

However, intervals in drier mountain big sagebrush communities (approximately 12 inches of precipitation) were likely longer (fig. 3-21). Both rates of establishment and growth of pinyon and juniper can be high in these cool and moist, deep soil sites (Barney and Frischknecht 1974; Campbell 2016; Johnson and Miller 2006). Fire and competition from perennial herbs were the most likely factors in limiting woodland expansion into these cool and moist mountain big sagebrush and mountain brush communities. And competition from undisturbed herbaceous layers may have slowed the rates of tree establishment, allowing for less frequent fire return intervals to maintain a persistent shrub-steppe community (Wright et al. 1979).

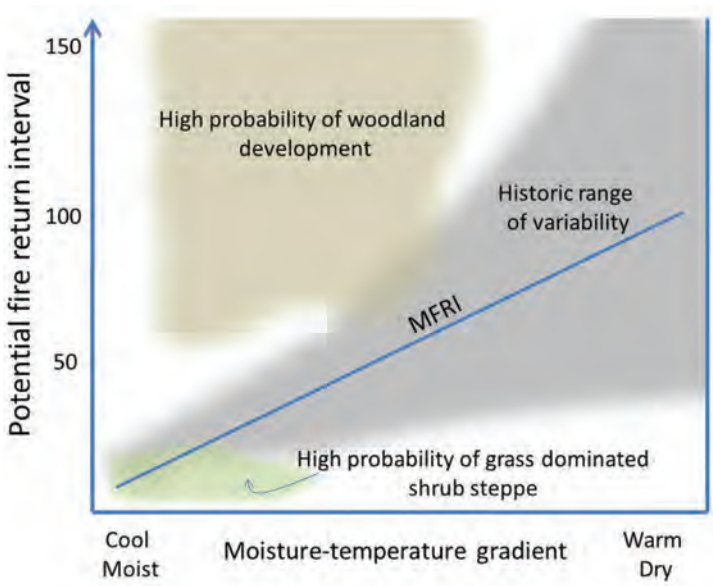

Figure 3-21—Conceptual model illustrating the range of historic potential mean fire return interval (MFRI) and historic range of variability (HRV) as it changes across a temperature and moisture gradient for sagebrush steppe (gray), persistent woodland (brown), and grassland (green). Fire frequency is a function of moisture and temperature, which influences fuel structure, composition, and biomass in addition to ignition. Persistent vegetation occupying the gray area would likely be a sagebrush herbaceous mix with the relative species abundance depending on time since fire (from Miller et al. 2011).

Presettlement Fire Regimes: Pinyon and Juniper Savanna

In the Colorado Plateau, where the proportion of warm season bunch and sod grasses can increase in composition in relation to the shrub layer as a result of increased summer precipitation, pinyon and juniper savannas and highland grasslands became more common (fig. 3-22; Nicol 1937; West 1999). In northern Arizona, early observations indicated that pinyon and juniper were expanding into grassland communities with the presettlement trees often occupying the rocky knolls and ridges (Leopold 1924; Nicol 1937). Fire history studies in pinyon and juniper savannas are limited (Romme et al. 2009). But a recent study in Arizona pinyon and juniper savannas reported presettlement mean fire return intervals of 7.8 years (Margolis 2014). The decline of both fire and perennial grass competition, which corresponded with the regional introduction of livestock, likely triggered the rapid increase in tree establishment across these savannas in the Colorado Plateau and Southwest (Margolis 2014; Nicol 1937; West 1984).

Postsettlement Woodland Expansion and Infill

Over the past 200 and more years, but prior to Eurasian settlement, evidence suggests pinyon and juniper woodlands were slowly expanding and infilling (Cole et al. 1997; Eisenhart 2004; Landis and Bailey 2008; Mehringer and Wigand 1990; Wigand et al. 1995; P.J. Mehringer, Retired Paleobotanist, Washington State University, Pullman, Washington, personal communication, 1990). This rate of infill increased shortly after Eurasian settlement, with rates of tree expansion into adjacent sagebrush ecosystems (fig. 3-23) and infill into established woodlands, peaking in the early 1900s across the Great Basin and Colorado Plateau (figs. 3-15, 3-16, 3-24; table 3-4; Barger et al. 2009; Biondi and Bradley 2013; Floyd-Hanna et al. 2004; Margolis 2014; Miller et al. 2008). Recent expansion rates appear to be greater than those occurring in the past (Cole et al. 1997; Mehringer and Wigand 1990; Miller and Wigand 1994). The rapid increase in tree expansion and infill is often attributed to climate, grazing, and reduced fire occurrence where surface fuels were once adequate to support surface fires.

Figure 3-22—Fire history studies in pinyon and juniper savannas are limited, but a recent study in Arizona pinyon and juniper savannas reported presettlement mean fire return intervals as relatively short. Northern Arizona. (Photo by Rick Miller, Oregon State University.)

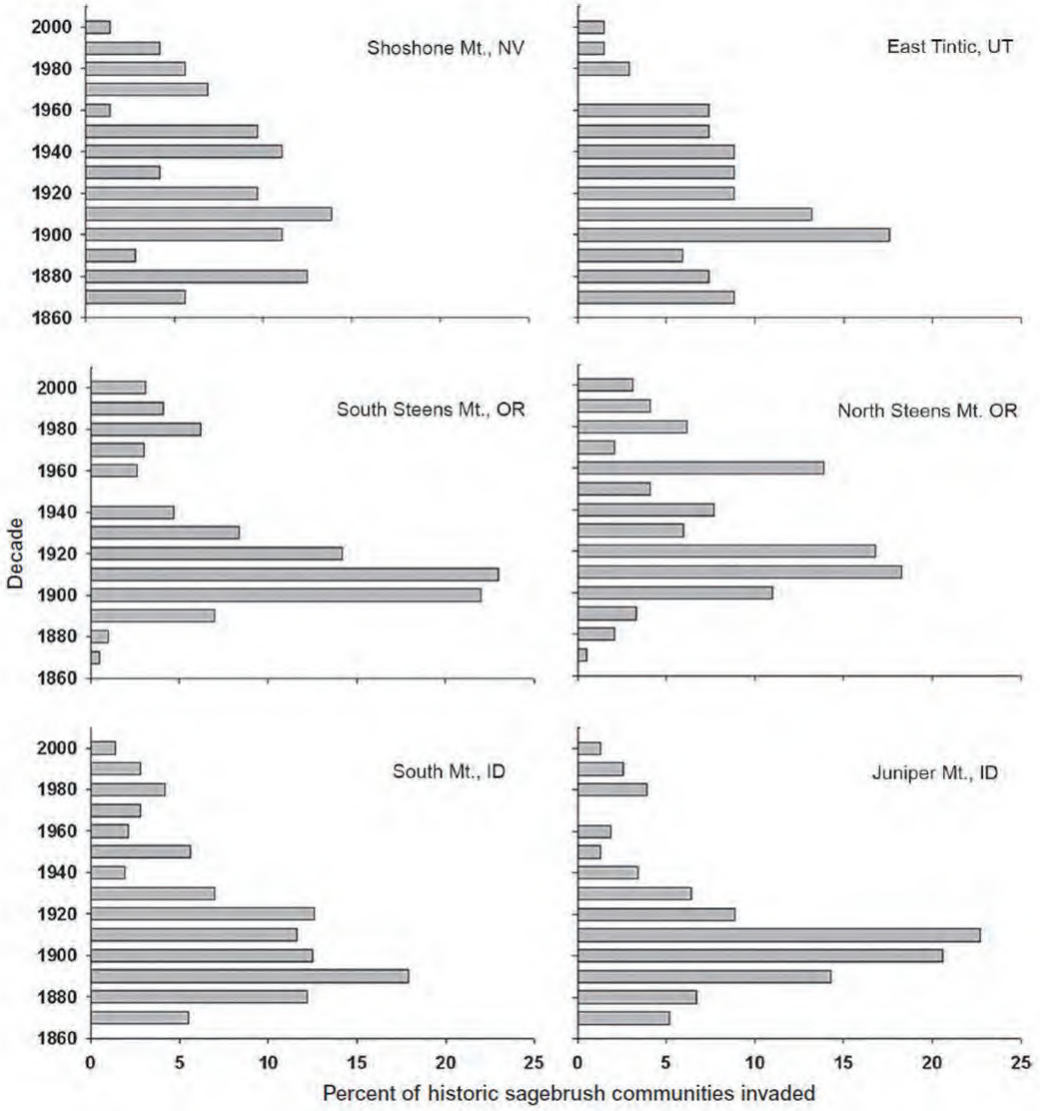

Figure 3-23—The relative proportion of pinyon and juniper expansion into historic sagebrush steppe stands lacking evidence of presettlement trees by decade between 1860 and 2000 (adapted from Miller et al. 2008).

However, consensus is lacking as to the relative importance of grazing, fire, and climate in recent expansions. Some attribute expansion primarily to natural climate phenomenon (Barger et al. 2009; Biondi et al. 2013; Floyd et al. 2004). Some attribute apparent woodland expansion to reestablishment following stand removal events, including extensive tree harvests through the Comstock period in the late 1800s (Lanner 1976; Young and Budy 1987). And others have attributed the recent increase to a combination of climate during the late 1800s and early 1900s and grazing—resulting in the reduction of fire occurrence (Baisan and Swetnam 1997; Heyerdahl et al. 2006; Miller and Rose 1999; Savage and Swetnam 1990; Swetnam et al. 2001; Touchan et al. 1995). Woodland expansion has also been linked to rising atmospheric CO_2 levels in the second half of the 20th century (Johnson et al. 1993; Soulé and Knapp 1999). Increased CO_2 levels can increase water-use efficiency in conifers, resulting in denser tree canopies (Knapp et al. 2001; Soulé and Knapp 1999).

Climate has always been a strong driver of woodland dynamics over time and space—but the effects of climate on woodland infill and expansion cannot be separated from fire,

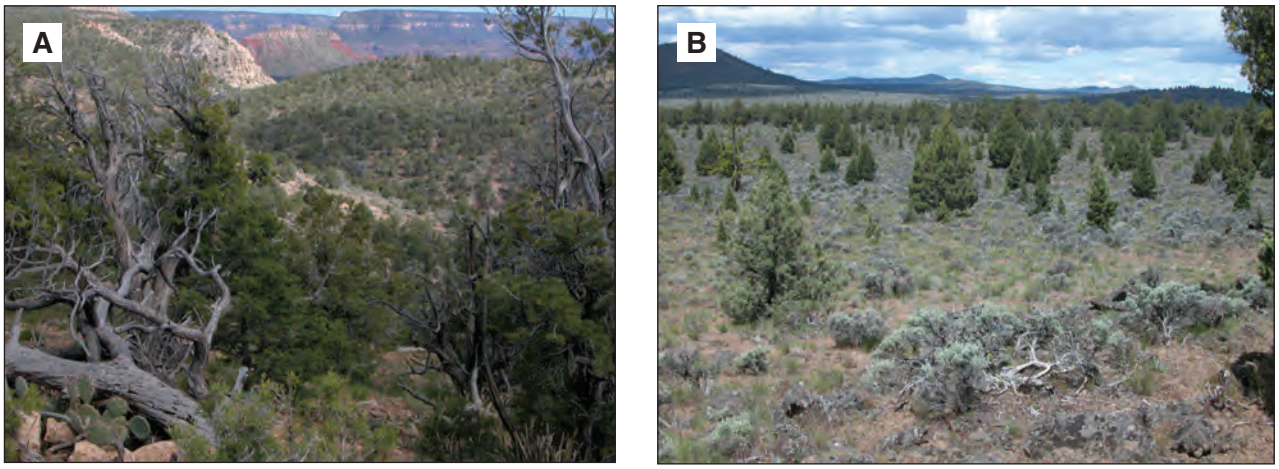

Figure 3-24—Many of the postsettlement trees we see today across the Colorado Plateau and Great Basin were established during a wet period between 1890 and 1920. (A) There has been a significant increase in tree density in this old-growth woodland on the Kaibab Plateau since the 1900s. (B) The mature trees on this site established during the first part of the 20th century expanding into mountain big sagebrush and Idaho fescue in central Oregon on moderately deep sandy loams. Presettlement trees, logs, and stumps are present but less than 1 per acre. (Photos by Rick Miller, Oregon State University.)

grazing (Caracciolo et al. 2016; Leopold 1924; Wright et al. 1979), insect infestations, and disease (Swetnam and Betancourt 1998). And variation in climate can increase or decrease anthropogenic effects on ecosystems (Swetnam and Betancourt 1998). With the exception of climate, the relative importance of the other attributing factors will vary within watersheds and across geographical regions.

Packrat middens, pollen, and tree-ring chronology evidence suggest an unprecedented increase in the expansion and infill of pinyon and juniper woodlands since the late 1800s (table 3-4; Cole et al. 1997; Landis and Bailey 2005; Mehringer and Wigand 1990; Miller and Wigand 1994). The presence or absence of stumps, snags, and logs, and the ratio of old-growth to young woodlands and trees across the Intermountain West, strongly suggest both infill and expansion significantly increased in the late 1800s and early 1900s (postsettlement) before declining to slower rates (figs. 3-15, 3-16). In the northwest, Mehringer and Wigand (1990) reported a fivefold increase in pinyon and juniper pollen from the late 1800s to 1980. In the Colorado Plateau, Cole et al. (1997) reported that changes in woodlands during the Holocene were minor compared to the last 200 years. Expansion and infill across the Great Basin and Colorado Plateau occurred as a gradual increase in the 1700s and early 1800s but as a rapid increase in the late 1800s, with a peak frequently occurring in the early 1900s. The majority of dendrochronology studies conducted across the Great Basin and Colorado Plateau reported increased tree abundance along this timeline.

Expansion of postsettlement woodlands into presettlement sagebrush ecosystems in Oregon, Nevada, Idaho, and Utah (figs. 3-23, 3-24b; Miller et al. 2008; Strand et al. 2008; West 1984), aspen communities in southeastern Oregon, northeastern California, and northwestern Nevada (Wall et al. 2001), and riparian and meadow vegetation in southwestern Utah (Cottam and Stewart 1940) peaked between 1890 and 1920 (fig. 3-16). In many postsettlement woodlands, the existence of presettlement trees, logs, snags, and stumps are missing, or they are only found at low densities on ecological sites that were likely persistent sagebrush communities prior to the late 1800s (Johnson and Miller 2008; Miller and Heyerdahl 2008; Miller and Rose 1995, 1999; Miller et al. 2008; Nicol 1937; Weisberg et al. 2008).

There is also no evidence that mature pinyon or juniper were common in meadow, riparian, or aspen communities, prior to 1880 (Cottam and Stewart 1940; Wall et al. 2001). Expansion of pinyon and juniper occurred both up and down slope (Bradley and Fleischman 2008; Cottam and Stewart 1940; Hattori and Thompson 1987; West 1984; Woodbury 1947). However, Lanner and Frazier (2011) found no evidence of downslope movement of pinyon and juniper woodlands based on current boundaries with early observations of Coville (1893) and Wilson (1941). But these early observations did not clearly define the lower limits of woodlands. The greatest rates of expansion have occurred in the productive cool and moist mountain shrublands with mollic soils (Campbell, USDA NRCS data 2015; Johnson and Miller 2006; West 1984).

By the end of the 20th century, tree densities were more than 600 percent of the historic estimate in sagebrush ecosystems (Cottam and Stewart 1940; Gedney et al. 1999) and in desert grasslands once dominated by tobosa and blue grama grass (Margolis 2014). Since the 1920s, the rate of tree establishment has declined, but expansion and infill are still occurring in a generally warming and more arid climate. This appears to be a contradiction from the past when woodlands usually declined during shifts from cool and moist to warm and dry climates (Wigand 1987) and suggests that increasing atmospheric CO_2 concentrations are an important factor in current woodland expansion.

Tree Expansion vs. Reestablishment From Harvest in the Late 1800s

Tree expansion into previously nonwoodland communities across Nevada and Utah is somewhat clouded by the reestablishment in persistent woodlands harvested during the Comstock Mining era between 1863 and 1908, peaking between 1884 and 1891 (Hattori and Thompson 1987; Strachan et al. 2013). For example, tree-age chronology studies by Blackburn and Tueller (1970) occurred near historic mining sites and likely included both harvested and nonharvested areas, based on the presence or absence of presettlement trees within their plots (sidebar 5). Estimates of the amount of pinyon and juniper cut for charcoal fuel in the Great Basin during this Comstock era range from 600,000–750,000 acres (Lanner 1981; Young and Budy 1979), which represents 3.4–4.25 percent of the total acreage of woodlands in Utah and Nevada (fig. 3-25; Tueller et al. 1979). Modeling results and historical harvesting evidence indicate that heavy harvesting of pinyon and juniper primarily occurred close to the mining districts, and quickly decreased with distance (Ko et al. 2011). For example, in the Eureka, Nevada, mining district, half of the presettlement woodlands were not harvested 10 miles from the mine. Steepness of terrain also limited tree harvesting. Harvesting was greatest on slopes less than 15 percent and rapidly declined on slopes greater than 25 percent. Based on the tree-ring records, old stumps, and mining construction materials, Hattori and Thompson (1987b) concluded that severe historic deforestation depicted by historic accounts and photographs may have been exaggerated because of their proximity to mining settlements.

The proportion of young versus presettlement woodlands strongly supports significant pinyon and juniper expansion and infill beginning since the late 1800s. A USDA Forest Service inventory in Utah and Nevada estimated that woodlands between 40–120 years old accounted for 67 percent of all pinyon and juniper stands (O'Brien and Woudenberg 1999). In a recent inventory of Nevada's forests, 62

Sidebar 5

What happened to the stumps?
When old trees die or when stand-replacing fires occur, a considerable number of stumps, logs, snags, and large charcoal pieces remain on site and persist for centuries. But stumps are rarely found on many areas where trees were cut during the Comstock era. Lanner (1976) suggests trees were cut to ground level, but this is highly unlikely since this method quickly dulls a saw blade and is extremely hard on the back and knuckles. Another extremely labor-intensive possibility is that stumps were excavated. This may have occurred immediately adjacent to the mining sites (Hattori and Thompson 1987b) but is doubtful across the hundreds of thousands of acres where stumps are missing. Another possibility is rapid stump decomposition. Kearns and others (2005) reported pinyon snags only persisted up to 25 years. However, Hattori and Thompson (1987b) crossdated (see Glossary) intact pinyon stumps near the Cortez Mining District cut between 1864 and 1932. Wood density, ratio of sapwood/heartwood, and aridity of the ecological site influence the rate of decomposition as does the age of the tree. The disappearance of these stumps remains a mystery.

Figure 3-25—Between 600,000 to 750,000 acres of pinyon were harvested for charcoal in Utah and Nevada in the late 1900s for extracting precious minerals. This represents approximately 3.4 to 4.25 percent of the total acres of woodlands in these two states. Panamint Range, eastern California. (Photo by Rick Miller, Oregon State University.)

percent of pinyon and juniper woodlands were reported to be less than 150 years old and 71 percent of pre- and postsettlement woodlands were experiencing infill (Menlove et al. 2016). Young stands in the Shoshone Mountains in central Nevada accounted for 57 percent, mixed age stands 33 percent, and old-growth 10 percent of woodlands (Weisberg et al. 2008). And, old-growth stands had considerable infill. In eastern California, young woodlands (less than 150 years old) accounted for 80 percent of the total area occupied by woodlands (Bolsinger 1989). Other studies reported that over 50 percent of woodlands (fig. 3-23) and trees (fig. 3-16) in Oregon, Idaho, Nevada, and Utah were relatively young—less than 150 years (Bradley and Fleischman 2008; Miller et al. 2008; Weisberg et al. 2007, 2008).

Comparisons of recent and early surveys and records estimate increases in postsettlement woodland area of more than 600 percent in Arizona (Margolis 2014) and similar increases between 1938–1988 in Oregon (Gedney et al. 1999) and 1864 and 1930 in southwestern Utah (Cottam and Stewart 1940). Based on these estimates, young woodlands accounted for well over half of the more than 20 million acres in eastern Oregon, eastern California, Nevada, and Utah. This exceeds the estimates of harvested acres in the late 1800s by 27 times. The limited distribution and abundance of charred snags, stumps, logs, and large charcoal across the Great Basin and Colorado Plateau in many young woodlands suggest the majority are not the result of tree replacement across millions of acres of persistent woodlands after stand-replacing events, but instead represent widespread expansion through new tree establishment in recent centuries. However, considerable variation in the ratio of pre- and postsettlement woodlands occurs geographically and regionally, with a higher proportion of presettlement woodlands in the Colorado Plateau where fire occurrence is considerably less (fig. 3-18; Board et al. 2018; Littell et al. 2009).

Potential Factors Influencing Postsettlement Expansion and Infill

The accelerated rate of woodland infill and expansion in the late 1800s and early 1900s was primarily driven by climate (fig. 3-16). But in addition to climate's direct effects on seed production (Redmond et al. 2012), seedling establishment (Chambers 2000; Johnsen 1962; Smith et al. 1975), and mortality (Breshears et al. 2005), the changes are also closely linked to climates effects on disturbance such as fire, competition, insects, and disease. Disturbance plays an important role in limiting the distribution of pinyon and juniper woodlands in nonwoodland ecological sites suitable for tree establishment and growth (fig. 3-24b; Leonard et al. 1987; Wright et al. 1979). Where soils and climate are suitable for tree establishment and growth, the frequency and severity of these disturbances influence the distribution and persistence of pinyon and juniper, as well as sagebrush, riparian vegetation, aspen, and meadow communities.

Climate

The accelerated rate of tree infill and woodland expansion in the late 1800s and early 1900s (table 3-4; figs. 3-15, 3-16, 3-23) is largely attributed to climate (Barger et al. 2009; LaMarche 1974). Following the Little Ice Age, the climate generally became milder and remained wetter into the early portion of the 1900s (Antevs 1938; Biondi et al. 2011; Gray et al. 2004; Graumlich 1987; LaMarche 1973; Wahl and Lawson 1970). In the early 1900s, between 1905 and 1917, moist conditions were persistent and widespread across the nine western states and southwestern Canada (Woodhouse et al. 2005). During the second half of the 20th century, conditions have generally become warmer and drier (fig. 3-26; Ghil and Vautgard 1991; Mann et al. 2009; Marlon et al. 2012; Mote et al. 2013; Woolfenden 1996).

These climate changes in the second half of the 20th century coincided with a decline in the rate of tree expansion and infill after 1920 across much of the Great Basin and Colorado Plateau (figs. 3-16, 3-23; table 3-4). The initiation of increasingly drier conditions by the 1920s occurred earlier in the northern Great Basin than the Upper Colorado River Basin (fig. 3-12a,b; Schwinning et al. 2008; Miller et al. 2011). The Southwest was generally wetter than the Great Basin during the 1930s, experiencing sporadic drought years until a persistent dry period during the 1950s and early 1960s (Grissino-Mayer 1995; Miller et al. 2011).

However, with generally drier conditions in the latter half of the 1900s in both the Great Basin and Colorado Plateau, tree chronology studies (table 3-4) and satellite imagery (Bradley and Fleischman 2008) show continued trends in expansion of pinyon and juniper woodlands, which defies past periods where warming and drying resulted in woodland declines (Wigand 1987). The continued woodland infilling and expansion in relatively warmer and drier conditions in the second half of the 20th century may be attributed to reduced competition from perennial grasses and higher levels of CO_2, which likely improve water use efficiency in pinyon and juniper trees (Ivans et al. 2006; Knapp et al. 2001).

However, the rate and extent of 20th century pinyon and juniper expansion are spatially variable across the Colorado Plateau and Great Basin, as is recent woodland decline. In western Colorado, widespread tree canopy decline occurred in pinyon and juniper woodlands between 7,500–8,500 feet, and a widespread increase between 5,900–7,400 feet (Manier et al. 2005). In addition, significantly greater tree mortality from drought-related causes has occurred across the Colorado Plateau of twoneedle pinyon compared to limited losses of singleleaf pinyon in the Great Basin (Biondi and Bradley 2013; Clifford et al. 2008).

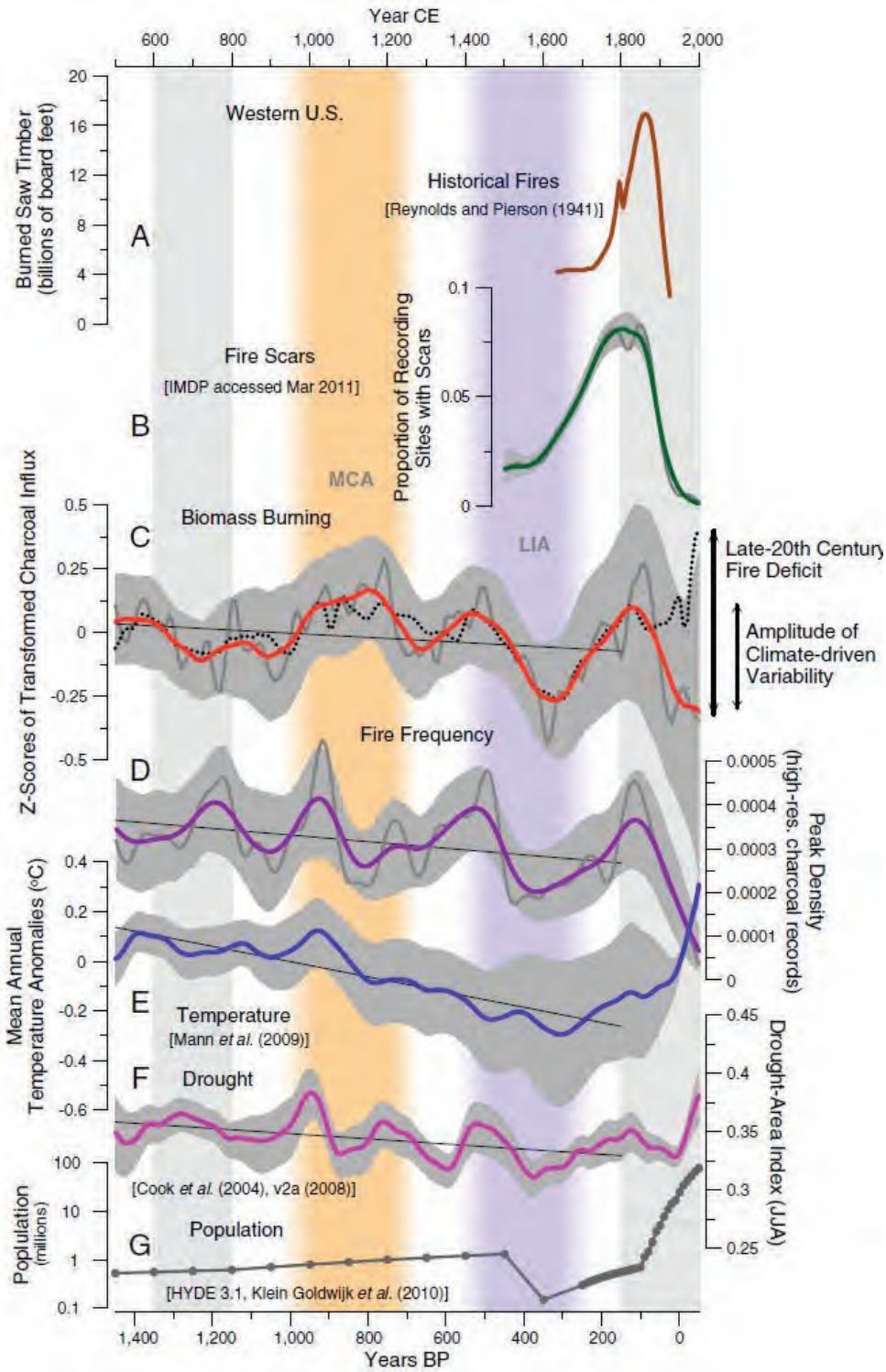

Figure 3-26—(A) Estimated historical saw timber affected by fires. (B) Smoothed proportions of dendrochronological sites recording fire scars (the green curve is based on locally fitting nearest-neighbor parameter of 0.25, while the gray curve is based on a parameter value of 0.10. (C) Smoothed and standardized 25-year (gray) and 100-year (red) trend line through standardized biomass burning records along with predicted biomass burning based on a GAM (black dashed line) fit to the 100-year biomass burning records. (D) Smoothed peak density (inferred fire frequency) from charcoal values (E) Smoothed gridded temperature anomalies for the western United States. (F) Smoothed Palmer Drought Severity Index for the western United States. (G) Population estimates for the western United States. All smoothed curves are plotted with 95 percent bootstrap confidence intervals (from Marlon et al. 2012).

Fire, Climate, and Grazing

Scientists disagree on the role and importance of fire and grazing in recent woodland expansion and infill across the Great Basin and Colorado Plateau (Baker 2011; Miller et al. 2011).

This is largely a result of:

1) Difficulties related to separating the direct and indirect effects of climate.
2) Unclear distinction often made between presettlement or persistent woodlands and recently expanded woodlands into historic nonwoodland communities.
3) Unclear distinction between recently expanded woodlands and reestablishment in persistent woodlands following stand-replacement events.
4) Geographic, regional, and local differences in disturbance regimes acting to control woodland expansion or contraction.
5) A wide range of variation in woodland structure, composition, and net-primary productivity (the rate at which all the plants in an ecosystem produce net useful chemical energy) in both time and space.
6) Issues of scale and landscape heterogeneity, especially as they relate to fire rotation and fire return interval interpretations.
7) Limited evidence of historical fire regimes in both time and space across semiarid plant communities, especially shrubland ecosystems.

Climate conditions in the late 1800s and early 1900s were ideal for cone production, tree-seedling establishment, and rapid growth rates (Eisenhart 2004; Fritts and Ziangdig 1986; LaMarche 1974; Redmond et al. 2012), especially during the persistently wet period in the West from 1905–1917 (Woodhouse et al. 2005). This wet period coincided with peak pinyon and juniper establishment reported in numerous chronological studies in the Great Basin and Colorado Plateau (table 3-4). But increased moisture would also have resulted in the accumulation of fine surface fuels and increased fuel continuity in the absence of heavy livestock grazing in the early 1900s. Antecedent wet years are especially important in increasing fuel continuity in communities with limited surface fuels and relatively long fire return intervals (Miller and Heyerdahl 2008; Miller and Rose 1999). Fine fuel accumulation in wet years has been closely linked to widespread large fires (Abatzoglou and Kolden 2013; Allen et al. 1995; Baisan and Swetnam 1990, 1997; Brown et al. 2008; Grissino-Mayer and Swetnam 2000; Miller and Rose 1999; Swetnam and Betancourt 1998). Unlike forested systems, fine fuel production was found to be more important than drought conditions for widespread fires in the semiarid West (Crimmins and Comrie 2004).

The majority of fire scar chronologies and tree-ring data indicate a decline in widespread surface fires in the West beginning in the late 1800s, which suggests postsettlement fires were largely eliminated (Allen et al. 2008a; Baisan and Swetnam 1990; Biondi et al. 2011). Fine fuel reductions by heavy livestock grazing during the late 1800s and early 1900s coincided with this dramatic decline in fire occurrence (Allen et al. 2008a; Baisan and Swetnam 1997; Gruell et al. 1994; Heyerdahl et al. 2006; Miller and Rose 1999; Savage and Swetnam 1990; Swetnam et al. 2001; Touchan et al. 1995). Climate changes alone were not likely sufficient to completely eliminate widespread surface fires (Swetnam et al. 2001). In addition to fine fuel reductions from grazing, fire suppression efforts and the near elimination of burning by Indians also likely contributed to the unprecedented decline in fire in the late 1800s across the Intermountain West. The sudden decline in fire occurrences in the late 1800s was like no other in the last 3,000 years (fig. 3-26; Marlon et al. 2012). The magnitude and importance of historical Native

American burning may have had implications from moderate to significant (Griffen 2002; Kay 2007; Keeley 2002; Pyne 1982; Robbins 1999; Stewart 2002) to minimal (Baker 2002; Vale 1975). Likely the degree of burning varied regionally (Swetnam et al. 2001) with tribal culture, fuels and types of vegetation, and food resources.

The impact of grazing on historic fire regimes also varied across the landscape, having little effect where surface fine fuels were insufficient to support fire spread, resulting in historically long fire return intervals (fig. 3-27; Barger et al. 2009; Huffman et al. 2008; Miller and Heyerdahl 2008; Waichler et al. 2001). The amount of woodland infill between grazed and ungrazed mesas in Utah was no different where fine surface fuels were already inadequate to support surface fires (5–6 percent cover) (fig. 3-27; Barger et al. 2009). In northern California, biomass of fine surface fuels was 100 pounds per acre in a presettlement woodland where the fire return interval exceeded 100 years (Miller and Heyerdahl 2008). In adjacent pine-fescue and mountain big sagebrush-fescue communities supporting 1,200 to 2,350 pounds per acre of fine surface fuels, mean fire return intervals were less than 15 years (Miller and Heyerdahl 2008). Fine fuel loads in mountain big sagebrush communities generally range between 1,000–3,000 pounds per acre (Mahalovich and McArthur 2004; Miller and Heyerdahl 2008; Passey et al. 1982; Shiflet 1994), which is more than adequate to support fire spread (Bunting et al. 1987; Evers et al. 2013; Gruell et al. 1986).

Grazing and Plant Competition

In the early 1900s, during his time with the USDA Forest Service in Arizona, Leopold (1924) wrote, "These ranges had never been grazed and they grazed them to death … the removal of the grass competition and fire damage brought in the reproduction [of trees]." Others also observed a decline in perennial grass cover from heavy grazing in the early 1900s, which coincided with the expansion of young woodlands (Emerson

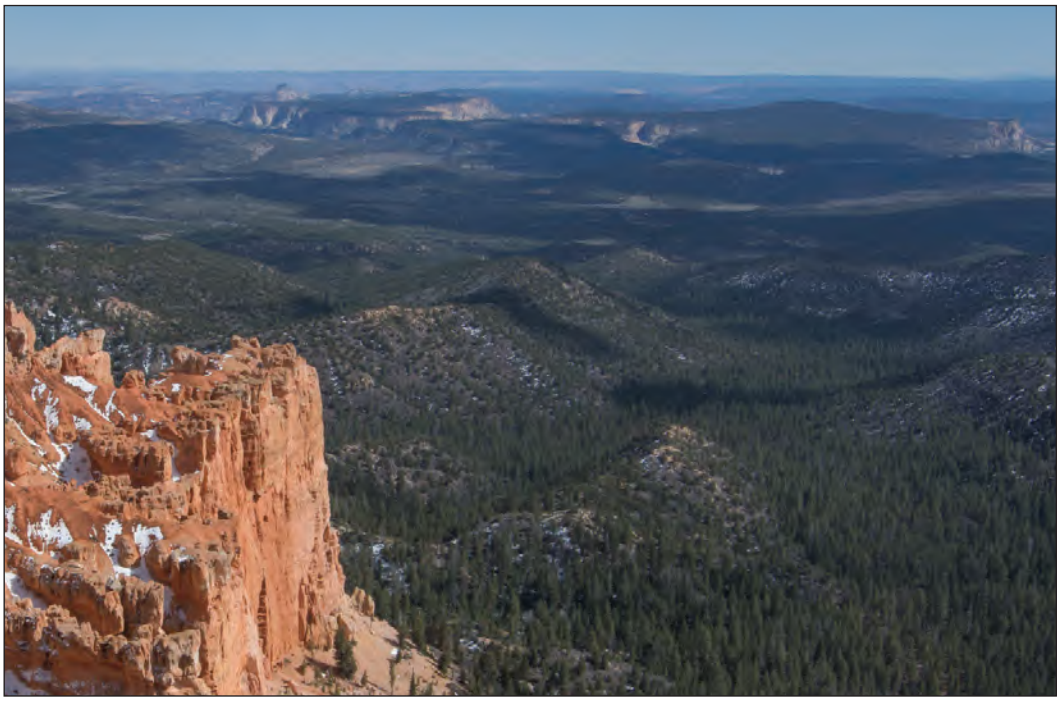

Figure 3-27—Just below the horizon are the ungrazed No-Man's mesa (left) and the grazed Deer mesa (right), where stand structures are similar. Both mesas historically had insufficient surface fuels to support fire spread, resulting in long fire return intervals, so grazing had little impact on the fire regime. Bryce Canyon looking south, Utah. (Photo by Rick Miller, Oregon State University.)

1932; Nicol 1937; Woodbury 1947). In several studies comparing historically grazed and ungrazed areas, pinyon and juniper density and canopy cover were greater in grazed areas (Guenther et al. 2004; Madany and West 1983; Shinneman and Baker 2009; Soulé et al. 2004). In the Grand Staircase Escalante National Monument, Utah, there was no difference in tree densities between grazed and ungrazed sites, but tree basal area was greater, and there was a significant reduction in perennial grasses on grazed compared to ungrazed high mesa sites (Barger et al. 2009; Harris et al. 2003).

Studies in ponderosa pine forests found that cool season grasses were very competitive with pine seedling establishment (Pearson 1934, 1942; Rummell 1951). Few small pines occurred in ungrazed areas, with a dense sod of perennial grasses compared to areas with depleted grass cover (Rummell 1951). Simulation modeling in woodlands across the Intermountain West identified grazing as a key factor in juniper encroachment by the way it reduced perennial grass and shrub cover, reduced fire occurrence, and disseminated pinyon and juniper seed (Caracciolo et al. 2016). Wright et al. (1979) proposed that the combined effects of presettlement droughts and perennial grass competition slowed the rate of woodland expansion and infill, which allowed longer fire return intervals to limit tree establishment. Depletion of perennial grasses and increased shrub canopy also augment woodland expansion by increasing the availability of safe sites for tree-seedling establishment. Shrubs provide safe sites for tree-seedling establishment by mediating temperatures and reducing competition from grasses (Burkhardt and Tisdale 1976; Johnsen 1962; Miller and Rose 1995; Soulé and Knapp 2000; Soulé et al. 2004).

Changing Fire Regimes Since 1980

Since 1980, when consistent and reliable reporting of wildfire ignitions and size began, total area burned and average size of individual fires across the West have increased (Brooks et al. 2004; Dennison et al. 2014; Littell et al. 2009; Miller et al. 2011; Morton et al. 2013; Westerling et al. 2006). This short record and high interannual variability make interpreting potential changes in fire regimes difficult in persistent woodlands where very long fire return intervals are typical. Still, there are indications that fire size and frequency have recently increased in pinyon and juniper woodlands (Board et al. 2018). Recent large fires in Mesa Verde covered 10 times the area they did in the past 150 years, and possibly the last 400 years (fig. 3-19; Floyd-Hanna et al. 2004). And the trend of larger areas burned in pinyon and juniper land cover types across the Intermountain West has significantly increased over the past 30 years (Board et al. 2018; Floyd et al. 2017). The increase is likely a result of increasingly warmer and drier conditions, 20th century increases in tree densities and canopies, and the increase in invasive annual grasses (Brooks et al. 2004; Westerling et al. 2006). The increase in erratic annual weather patterns influencing fuels and ignition can also influence fire regimes.

Postsettlement Woodland Decline

In the absence of stand-replacement disturbances, mortality in persistent pinyon and juniper woodlands can be less than 1 percent per century (Landis and Bailey 2005; Menlove et al. 2016; O'Brien 1999, 2002; Waichler et al. 2001). However, episodic stand-replacement or substantial thinning events at local and mesoscales do occur and are often linked to drought and drought-related disturbances (Furniss and Carolin 1977; Swetnam and Betancourt 1998). These episodic events are often connected to variations in climate, which are often synchronized with fire and insect infestations resulting in widespread tree die-offs (Breshears et al. 2005; Gaylord et al. 2013; Shaw 2006; Swetnam and Betancourt 1998). There have been 5 major droughts in the West during the 20th and 21st centuries (Betancourt et al. 1993; Breshears et al. 2005; Herford et al. 2002; Koepke et al. 2010).

The drought between 1942 and 1957 (fig. 3-12b) was the most severe in the past 400 years (Herford et al. 2002; Swetnam and Betancourt 1998). And the beginning of the 21st century began with a severe drought (from 2000 to 2003), resulting in 40-80 percent tree mortality across the Colorado Plateau (Breshears et al. 2005). A very recent report suggests the Southwest has been in a severe drought for the past 19 years (1999-2018) and much of the rest of the West for nearly the same time (Meyer 2018).

Although mortality can be relatively widespread, it typically differs among geographical regions and between pinyon and juniper. Die-offs during the drought of the early 2000s resulted in less than 10 percent mortality of singleleaf pinyon in the Great Basin (Biondi and Bradley 2013) compared to more than 50 percent in twoneedle pinyon across the Colorado Plateau (Breshears et al. 2005; Mueller et al. 2005a; Shaw et al. 2005). During this time, the large proportion of tree mortality was pinyon—with Utah, Rocky Mountain, and oneseed junipers suffering considerably less (Shaw et al. 2005). Mortality of mature reproductive twoneedle pinyon was 60 percent in Colorado, 74 percent in Arizona, and 94 percent in New Mexico—compared to less than 10 percent mortality in mature juniper (Floyd et al. 2009). The majority of pinyon trees were infested with bark beetles. Juniper had little infestation of insects and fungi. Dissimilarities in drought-related mortality between pinyon and juniper is largely attributed to differences in drought avoidance (Breshears et al. 2008a; Linton et al. 1998; Miller and Shultz 1987) and vulnerability to insect infestations (Floyd et al. 2009).

The relationship between drought-related mortality and tree density has been reported to range from minimal to significant (Clifford et al. 2008; Floyd et al. 2013; Greenwood and Weisberg 2008; McMillin et al. 2008; Negrón and Wilson 2008). In evaluating this relationship across spatially diverse woodlands, one must consider the capacity of the site to support trees—which varies considerably (Miller et al. 2000). Drought-related mortality in the Southwest may have been intensified by infill that has occurred across the majority of pinyon and juniper woodlands across the West during the 20th century (fig. 3-16; Barger et al. 2009; Biondi and Bradley 2013; Floyd-Hanna et al. 2004; Margolis 2014; Miller et al. 2008). The effect of elevation on drought-related mortality is also unclear. Greater mortality of twoneedle pinyon during the 2000-2003 drought was reported at lower elevations in Arizona, Utah, and Colorado (Cole et al. 2008a; McMillin et al. 2008). However, Breshears et al. (2008b) found elevation and mortality of twoneedle pinyon was positively correlated with elevation. Other site characteristics such as soil, seasonal patterns in precipitation, and temperature may be confounding the relationship between mortality and elevation.

SECTION 4: ECOHYDROLOGY OF PINYON AND JUNIPER WOODLANDS

Summary

The changes occurring throughout pinyon and juniper woodlands pose important ecohydrologic ramifications for plant communities (Pierson and Williams 2016; Wilcox and Breshears 1995). The broad variety of climate, soils, and topography in these ecosystems result in a wide range of hydrologic function. Woodlands can be generally classified either as “resource conserving” or “nonconserving” (Wilcox et al. 2003a). Resource conserving communities occur when ample vegetation and groundcover limit runoff and soil loss, promoting ecohydrologic resilience. Nonconserving or “leaky”

communities typically have extensive bare ground connectivity, which promotes runoff and soil loss. Woodlands intermediate to these two endpoints may transition from one conserving state to another following disturbance or drought events that changes the amount and structure of surface cover.

The resilience to remain or return to resource conserving is closely linked to an area's soils, climate, and topography. Throughout much of the semiarid Intermountain Region, pinyon and juniper are expanding into sagebrush ecosystems and infilling into persistent woodlands. Tree expansion and infill can result in reduced understory vegetation, increased connectivity of bare ground, and amplified runoff and soil loss.

Increased frequency of droughts and heavy fuel loads increase the threat of high-severity wildfires, which have significant adverse impacts on ecohydrological process. Initial ecohydrologic and erosion impacts of tree reduction by fire, mechanical treatments, or drought depend on: (1) the degree to which the vegetation and ground cover structure are altered, (2) initial site conditions, and (3) ecological site attributes.

In rain- to snow-dominated climate regimes, plot- and hillslope-scale studies suggest that burning commonly increases the risk of runoff and soil erosion-generating events by reducing surface cover structure and increasing connectivity of bare ground. This risk is likely greatest for sites commonly subjected to intense summer thunderstorms. Risk declines over time with vegetation and ground recovery (commonly within 5 years).

Topography and soils also influence potential erosion. The literature spanning all regions indicates that mechanical tree-removal treatments can initially improve infiltration and limit hillslope runoff and erosion if tree debris is sufficiently distributed into bare patches and in contact with the soil surface (Williams et al. 2019). Historic and recent research on drought-related vegetation transitions has documented transformative changes in ecohydrologic function that facilitate site degradation. These studies highlight the need to identify sites approaching the tipping points and management practices that increase resilience ahead of drought, fire, beetle infestations, invasive weeds, and other disturbance events. When ecological site characteristics are considered, successful tree-reduction treatments on woodland-encroached sagebrush rangelands can improve vegetation structure and ecohydrologic function. Improved ecohydrologic function on these landscapes further enhances the vegetation and ground cover structure and improves ecosystem resistance and resilience to invasive plants and disturbances.

Historical and current literature is inconclusive regarding tree-removal impacts on groundwater availability (Deboodt 2008; Kormos et al. 2017a; Ochoa et al 2018; Niemeyer et al. 2016). Studies conducted in the Great Basin and Colorado Plateau indicate tree removal can increase soil water along a hillslope over a broad range in annual precipitation. However, the additional amount of available water typically declines in the first few to 4 years after tree removal. The literature suggests the annual precipitation requirement for such enhancements in available groundwater with tree reductions likely occurs at ranges from 8 to over 16 inches (200 to over 400 mm) for predominately cold-season precipitation regions in the Great Basin. In the Southwest, very limited work would suggest 16 inches or more is required to see a response in soil water. The literature is also limited and inconclusive regarding tree-reduction impacts on streamflow.

Great Basin studies indicate tree reduction can affect patterns of snow accumulation and melt and in doing so, influence the timing of streamflow (Kormos et al. 2017b). Other studies from the Great Basin suggest tree reductions may have little impact on streamflow but can temporarily increase groundwater. Literature on impacts of tree-removal treatments to increase streamflow for the southern Colorado Plateau and southwestern United States have reported mixed results, and there is no clear indication that tree removal in pinyon and juniper woodlands on sites with rain-dominated precipitation regimes will foster long-term increases in streamflow. Recent studies of drought-induced tree die-off in woodlands and

forests of the Colorado Plateau have reported reductions to no change in streamflow. To date, there is little evidence that drought-related changes to vegetation in pinyon and juniper woodlands significantly alter water availability at the annual time scale, particularly for the rainfall-dominated southwestern United States. In the Great Basin and northwestern Colorado Plateau, large-scale die-offs have not been reported and therefore ecohydrologic impacts of drought cannot be assessed for those regions.

Introduction

Ecohydrology processes in pinyon and juniper woodlands are based on the same principles as other semiarid communities where water and soil retention or losses are governed by the structure, amount and cover of vegetation, inherent soil and topographic attributes, and climate (fig. 4-1; Davenport et al. 1998; Kormos et al. 2017a; Ludwig et al. 2005; Niemeyer et al. 2016, 2017; Petersen et al. 2009; Pierson et al. 2007, 2010; Reid et al. 1999; Roundy et al. 2014a, 2014b; Urgeghe et al. 2010; Wilcox et al. 1988, 1996a, 2003a; Williams et al. 2014a, 2016a,b, 2019). Vegetation and groundcover affect the soil microclimate (Breshears et al. 1997a, 1998; Lebron et al. 2007), enhance infiltration (Cline et al. 2010; Pierson et al. 2010, 2013, 2014; Reid et al. 1999; Roundy et al. 2017; Wilcox et al. 2003a; Williams et al. 2014a, 2016a, 2019) and soil water recharge and storage (Bates et al. 2000; Mollnau et al. 2014; Ochoa et al. 2018; Roundy et al. 2014a; Young et al. 2013a,b), and protect the soil surface from raindrop impact and the erosive energy of overland flow (Cline et al. 2010; Pierson et al. 2007, 2010, 2013, 2014, 2015; Reid et al. 1999; Roundy et al. 2017; Williams et al. 2014a, 2016a,b, 2019). In contrast, bare patches on these landscapes rapidly shed water and erode during intense rainfall events (Cline et al. 2010; Petersen and Stringham 2008; Petersen et al. 2009; Pierson et al. 2007, 2010; Reid et al. 1999; Wilcox 1994; Wilcox et al. 1996a; Williams et al.

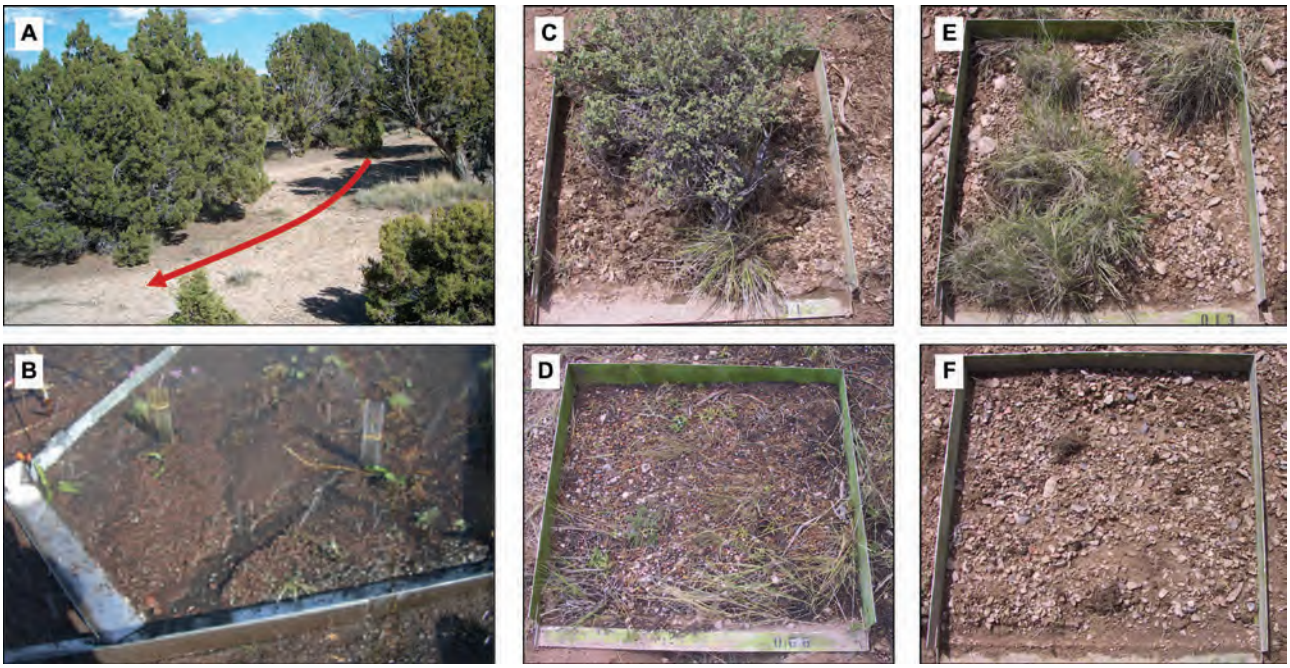

Figure 4-1—Photographs from a Utah juniper woodland showing the patchy structure of tree-covered area and bare intercanopy between trees (A), a bare intercanopy runoff plot with concentrated overland flow and rilling (B), and shrub (C), under tree canopy (D), grass covered interspace (E), and bare interspace (F) microsites. The red arrow in photograph A depicts the general direction of concentrated overland flow that commonly occurs during runoff generating events on these landscapes. (Figure modified from Pierson and Williams 2016.)

2014a). Bare patches exhibit different seasonality in wetting, drying, and evaporative losses than vegetated patches, which can also affect overall landscape productivity (Breshears et al. 1997a, 1998; Newman et al. 2010).

The amount and structure of vegetation, inherent soil properties, and topography regulate responses to water input at hillslope to watershed scales (Davenport et al. 1998; Kormos et al. 2017a; Roundy et al. 2014a, 2017; Wilcox et al. 1996a, 2003a; Williams et al. 2014b, 2016a,b). Wilcox et al. (2003a) characterize these semiarid woodland landscapes as either "resource conserving" (fig. 4-2), where the vegetation structure and conditions capture water and buffer runoff and soil loss, or "nonconserving" (fig. 4-3) where the vegetation structure and conditions promote loss of water and soil—and lead to site degradation. In this section, we discuss these relationships for pinyon and juniper woodlands in the Great Basin and Colorado Plateau, including some coverage of fundamental hydrology and erosion processes for rangelands. This synthesis focuses on the annual water budget and associated hydrologic components of woodlands and includes erosion concepts in concert with overland flow and runoff processes. We do not separate content for presettlement and postsettlement woodlands, as the literature addressing hydrologic processes is too limited for such a separation in the context of broad coverage of pinyon and juniper hydrologic and erosion processes. We do, however, provide a brief discussion of woodland hydrologic and erosion responses to tree-removal practices (Brockway et al. 2002; Cline et al. 2010; Hastings et al. 2003; Jacobs 2015; Nouwakpo et al. in review; Ochoa et al. 2018; Owen et al. 2009; Pierson et al. 2007, 2013, 2014, 2015; Roundy et al. 2014a, 2017; Williams et al. 2014a, 2016a,b, 2019)—aimed at restoring woodland-encroached landscapes—which is also discussed in Section 5 (Bates and Davies 2016; Bates and Svejcar 2009; Bates et al. 2017b; Havrilla et al. 2017b; McIver and Brunson 2014; McIver et al. 2014; Redmond et al. 2013).

Figure 4-2—Phase II, which still maintains an intact understory is an example of resource conserving. However, as trees continue to fill the community, the understory will decline, increasing bare ground and becoming nonresource conserving. Modoc Plateau, northeastern California. (Photo by Rick Miller, Oregon State University.)

Figure 4-3—Phase III, with depleted herbaceous vegetation, declining shrub canopy, and high level of bare ground, is nonresource conserving. The high amount and connectivity of bare ground limits water capture, resulting in increased runoff, sediment loss and loss of nutrients. Schell Creek Mountains, eastern Nevada. (Photo by Rick Miller, Oregon State University.)

Water Budget in Pinyon and Juniper Woodlands

The water budget—the amount of water a plant community captures, stores, and releases—is input minus output and equals the changes in water storage. The ability of a plant community or landscape to capture and store water is closely linked to ecosystem resilience. Generally, the water budget is determined for a hydrologic water year. Water years are commonly defined as October 1 to September 30, as this time period marks the end of the growing season and the start of water input for the next growing season.

Precipitation

Pinyon and juniper woodlands extend across a large region of the Great Basin and Colorado Plateau where geology, soils, and climate—especially amounts and seasonality of precipitation—are highly variable (table 4-1; figs. 2-1, 2-2, 4-4, 4-5). Pinyon and juniper generally occur in areas that receive 10–16 inches of precipitation in the Intermountain Region (see Section 2 on woodland distribution and ecological site characteristics). However, there are some notable exceptions in the Southwest.

Table 4-1—Locations plotted in figure 4-1 and figure 4-4 and respective references.

Site name	State	Latitude	Longitude	Reference
Camp Creek (CC)	OR	43.96° N	-120.34° W	Deboodt et al. 2008; Ochoa et al. 2018
Reynolds Creek (RC)	ID	43.05° N	-116.43° W	Niemeyer et al. 2016
South Mountain (SM	ID	42.67° N	-116.90° W	Kormos et al. 2017b
Porter Canyon (PC)	NV	39.46° N	-117.62° W	Stringham et al. 2018
Canyonlands (CL)	UT	38.83° N	-109.84° W	West et al. 2007, 2008
Beaver Creek (BC)	AZ	34.37° N	-111.42° W	Clary et al. 1974; Zou et al. 2010
Cibeque Ridge (CR)	AZ	34.01° N	-110.20° W	Ffolliott and Gottfried 2012
Sevilleta (SV)	NM	34.23° N	-106.31° W	Limousin et al. 2013; Plaut et al.2012

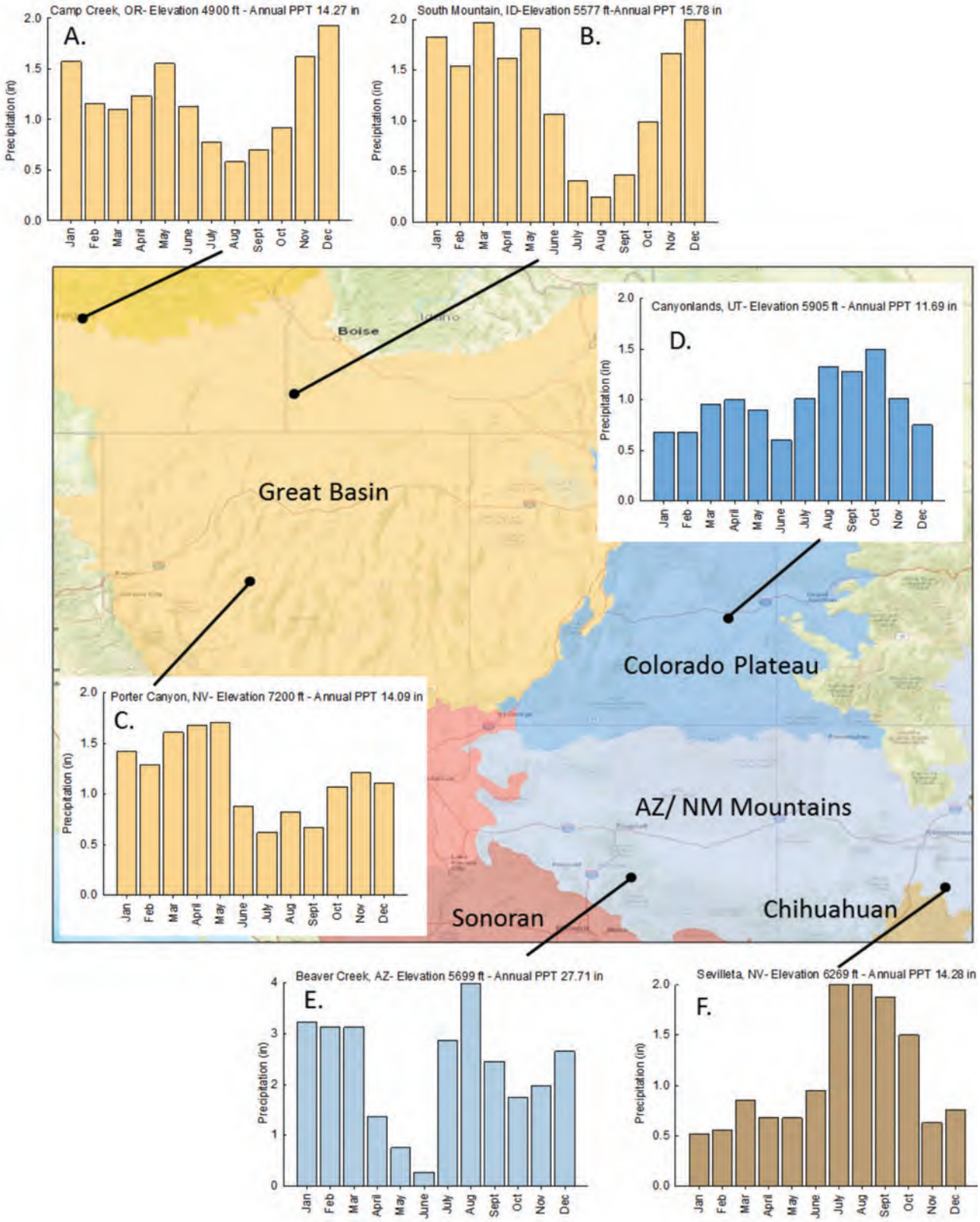

Figure 4-4—Mean monthly precipitation for six selected locations listed in table 4-1, inclusive of sites with a snow-dominated (A-C), mixed phase (D), and rainfall-dominated (E-F) precipitation regimes. Precipitation from 30-year monthly PRISM data, 800 m resolution (PRISM Climate Group 2018). (Figure modified from Williams et al. 2018b.)

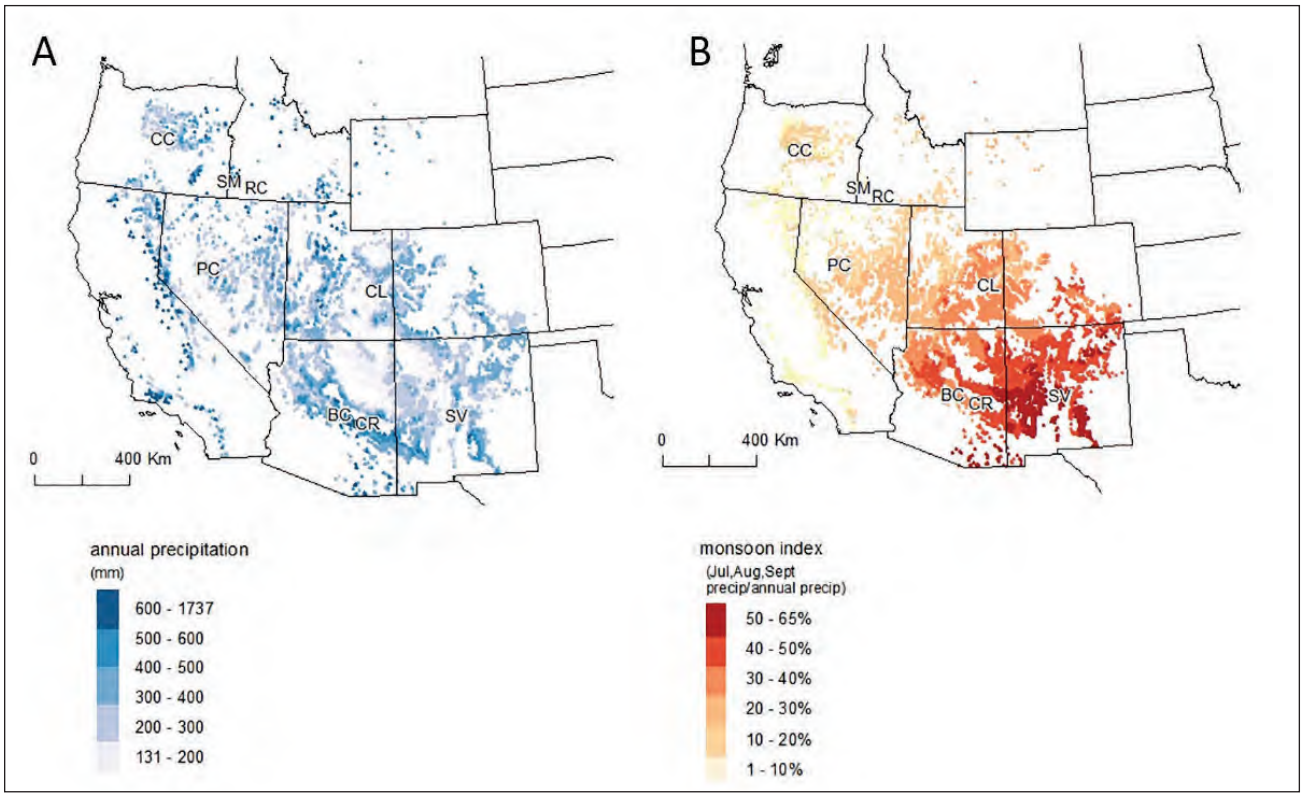

Figure 4-5—Maps of (A) average mean annual precipitation (shown in mm, 25.4 mm = 1 in) and (B) the monsoon index, which is the fraction of the annual precipitation that occurs in July, August, and September, across the pinyon and juniper domain in the western United States. Study sites from table 4-1 are depicted with site abbreviations. (Modified from Niemeyer et al. 2017; figure drawn by Tom Dilts, Great Basin Landscape Ecology Lab, University of Nevada-Reno.)

Precipitation in figure 4-4 is scaled the same for five locations on the y-axis, but Beaver Creek, Arizona (fig. 4-4e), receives nearly twice as much average annual rainfall. The seasonality of precipitation has been postulated to have important ecohydrological ramifications on woody plant expansion and treatments to remove woody plant species (Huxman et al. 2005). Specifically, it has been proposed that in regions where winter precipitation is the dominant input to the water budget (Mediterranean and cold-dominated climates), there is a greater potential to redistribute limited water resources with woody plant control. In these areas the growing season is largely decoupled from precipitation inputs so melting snowpack or winter rainfall are able to infiltrate and percolate to greater depths. In contrast, in summer-dominated rainfall systems, plants actively transpire shallow soil moisture delivered as rainfall (Huxman et al. 2005; Niemeyer et al, 2017). Alternatively, in these water-limited environments where pinyon and juniper exist, all water may be lost as evapotranspiration, regardless of seasonality.

This chapter reviews studies that address the ecohydrological implications of pinyon and juniper, which span these seasonally different regions. A map of the distribution of pinyon and juniper in these regions was redrawn from Niemeyer et al. (2017), which shows the range of mean annual precipitation (MAP) and percentage of rainfall that was delivered in July, August, and September (i.e., the monsoon index) across the regions (fig. 4-5).

Surficial Hydrology and Erosion Processes

Infiltration on Woodlands

Soil infiltration rates in woodlands are influenced by the amount and arrival rate of water at the ground surface; the ability of the soil to conduct water into and through

the soil; the slope, the roughness; and the chemical characteristics of the soil surface (Branson et al. 1981; Dingman 2014; Dunne and Leopold 1978; Hillel 1998). Infiltration is dynamic during an event, varying with changes in soil wetting and soil properties. In general, infiltration is more rapid in the early stages of water input into dry soil, decreases as the surface soil wets up, and approaches a relatively steady state (steady state infiltration rate) as soil becomes saturated (fig. 4-6).

Based on infiltrometer and rainfall simulation studies, infiltration rates and hydraulic conductivities for woodland soils vary at multiple scales within woodlands and across geographical regions (table 4-2; Cline et al. 2010; Lebron et al. 2007; Madsen et al. 2008; Petersen and Stringham 2008; Pierson et al. 2010, 2013, 2014; Roundy et al. 1978; Wilcox et al. 2003c; Williams et al. 2014a, 2019). Wilcox et al. (2003c) assessed unsaturated and saturated hydraulic conductivities of tuff-derived sandy loam to loam soils in canopy areas underneath trees and in vegetated and bare interspace areas. The assessments took place within the intercanopy between trees of twoneedle pinyon and oneseed juniper woodlands using infiltrometer (3-inch diameter) methodologies.

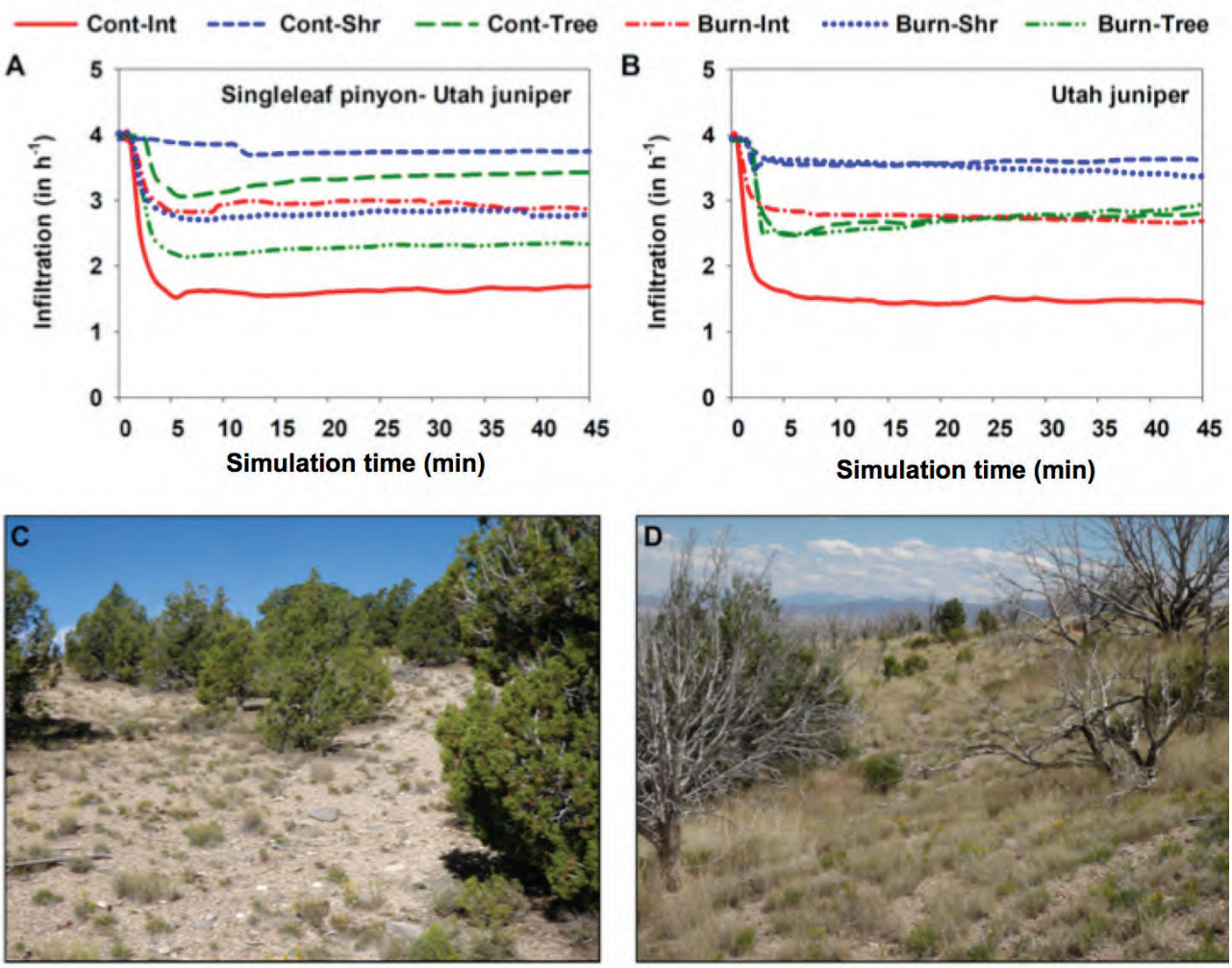

Figure 4-6—Infiltration (A and B) from rainfall simulation experiments (4.02 in h^{-1}, 45 min, 5.4 ft^2 plots) in untreated interspaces between shrubs and trees (Cont-Int), untreated shrub (Cont-Shr) and tree (Cont-Tree) canopy areas, burned interspaces (Burn-Int), and burned shrub (Burn-Shr) and tree (Burn-Tree) canopy areas in a singleleaf pinyon-Utah juniper woodland (A) and a Utah juniper woodland (B) 9 years following prescribed fire. Photographs at bottom of figure show the untreated Utah juniper woodland with extensive intercanopy area comprised largely of bare interspace and limited shrubs (C) and the same site 9 years after burning with good herbaceous cover within the intercanopy (D). Data from Williams et al. 2018a.

Table 4-2—Site characteristics, infiltration, runoff coefficients, and sediment yields reported for rainfall simulation and natural rainfall experiments in the western United States. Modified from Pierson and Williams (2016).

Study	Region (location) - community type	Microsite (plant)	Treatment /burn severity	Plot size (ft^2)	Slope (%)	Time since trmt. (mth)	Rain rate (in h^{-1}) /duration (min)	Rain type	WDPT (s)[a]	Soil water (%)[b] /conditions	Bare soil (%)	Canopy cover (%)	Ground cover (%)	Avg. Infiltration (in h-1)	Runoff coef. (%)[c]	Sed. yield (t ac^{-1})
Michaelides et al. 2009	Hot desert (Chihuahuan Desert, New Mexico) – mixed	Shrub canopy area (*Larrea tridentata*)	None	16	7	-	4.9/16–30	Artificial	-	7	79	65	21	-	55	0.43
O'Dea & Guertin 2003	Hot desert (Sonoran Desert, Arizona) – perennial grassland	Mixed grasses	Unb	323	3-Jan	-[d]	Variable	Natural	-	Dry	-	21	-	-	10	7.58[d]
			Mod	323	3-Jan	-[d]	Variable	Natural	-[e]	Dry	-	11	-	-	11	12.49[d]
		Mixed grasses	Unb	323	3-Jan	-[f]	Variable	Natural	-	Dry	-	37	-	-	14	8.03[f]
			Mod	323	1–3	-[f]	Variable	Natural	-[e]	Dry	-	29	-	-	14	9.81[f]
Craddock & Pearse 1938	Cold desert Great Basin, Idaho) - shrub steppe	Perennial bunchgrasses	None	217	30	-	1.8/60	Artificial	-	Dry	-	-	~ 35	-	1	~ 0.01
			None	217	30	-	3.6/30	Artificial	-	Dry	-	-	~ 35	-	1	~ 0.01
			None	217	40	-	1.8/60	Artificial	-	Dry	-	-	~ 35	-	< 1	~ 0.01
			None	217	40	-	3.6/30	Artificial	-	Dry	-	-	~ 35	-	< 1	~ 0.01
Craddock & Pearse 1938	Cold desert Great Basin, Idaho) - shrub steppe	Cheatgrass (*Bromus tectorum*)	None	217	30	-	1.8/60	Artificial	-	Dry	-	-	~ 20	-	10	0.14
			None	217	30	-	3.6/30	Artificial	-	Dry	-	-	~ 20	-	5	0.05
			None	217	40	-	1.8/60	Artificial	-	Dry	-	-	~ 20	-	26	0.22
			None	217	40	-	3.63	Artificial	-	Dry	-	-	~ 20	-	53	1.48
Craddock & Pearse 1938	Cold desert Great Basin, Idaho) - shrub steppe	Mixed grasses (*Lupinus* spp./*Stipa lettermanii*)	None	217	30	-	1.8/60	Artificial	-	Dry	-	-	~ 25	-	44	1.22
			None	217	30	-	3.6/30	Artificial	-	Dry	-	-	~ 25	-	57	2.28
			None	217	40	-	1.8/60	Artificial	-	Dry	-	-	~ 25	-	44	1.13
			None	217	40	-	3.6/30	Artificial	-	Dry	-	-	~ 25	-	55	2.09
Johnson & Blackburn 1989[g]	Cold desert Great Basin, Idaho) - shrub steppe	Sagebrush (*A. tridentata*)	None	351	10	-	2.5/60	Artificial	-	Dry	16	39	84	-	2	0.03
			None	351	6	-	2.5/60	Artificial	-	Dry	19	12	81	-	11	0.05
			None	351	9	-	2.5/60	Artificial	-	Dry	45	16	55	-	17	0.08
Pierson et al. 1994	Cold desert Great Basin, Idaho) - shrub steppe	Shrub canopy area (*A. tridentata*)	None	1	7	-	2.6/60	Artificial	-	4	0	-	100	-	2	~ 0.01
		Vegetated interspace	None	1	7	-	2.6/60	Artificial	-	4	4	-	96	-	23	0.1
		Bare interspace	None	1	7	-	2.6/60	Artificial	-	2	94	-	6	-	65	1.7
Pierson et al. 2002[h]	Cold desert Great Basin, Idaho) - shrub steppe	Shrub canopy area (*A. tridentata*)	Unb	5	35–60	12	2.6/60	Artificial	-	~ 14	7	88	93	-	11	~ 0.01
			Mod	5	35–60	12	2.6/60	Artificial	-	~ 5	97	11	3	-	34	0.13
			High	5	35–60	12	2.6/60	Artificial	-	~ 5	98	13	2	-	37	0.1
		Interspace	Unb	5	35–60	12	2.6/60	Artificial	-	~ 14	89	18	11	-	24	0.02
			Mod	5	35–60	12	2.6/60	Artificial	-	~ 5	95	16	5	-	26	0.05
			High	5	35–60	12	2.6/60	Artificial	-	~ 5	99	5	1	-	49	0.66

(Continued)

Table 4-2—(Continued).

Study	Region (location) - community type	Microsite (plant)	Treatment /burn severity	Plot size (ft^2)	Slope (%)	Time since trmt. (mth)	Rain rate (in h^{-1}) /duration (min)	Rain type	WDPT (s)[a]	Soil water (%)[b] /conditions	Bare soil (%)	Canopy cover (%)	Ground cover (%)	Avg. Infiltration (in h-1)	Runoff coef. (%)[c]	Sed. yield (t ac^{-1})
Pierson et al. 2001a, 2008b	Cold desert Great Basin, Nevada) - shrub steppe	Shrub canopy area (*A. tridentata*)	Unb	5	30–40	1	3.3/60	Artificial	200	7	1	100	99	-	30	0.05
			High	5	30–40	1	3.3/60	Artificial	102	1	99	1	1	-	37	0.18
		Interspace	Unb	5	30–40	1	3.3/60	Artificial	220	5	6	74	94	-	49	0.11
			High	5	30–40	1	3.3/60	Artificial	97	1	99	4	1	-	30	0.09
Reid et al. 1999	Temperate steppe mountains (Pajarito Plateau, New Mexico) – woodland	Vegetated interspace	None	22	6–12	-	Variable[i]	Natural	-	-	34	-	66	-	25[i]	1.33[i]
		Bare interspace	None	22	6–12	-	Variable[i]	Natural	-	-	84	-	16	-	37[i]	4.49[i]
		Tree canopy area (*P. edulis or J. monosperma*)	None	11	6–12	-	Variable[i]	Natural	-	-	0	-	100	-	8[i]	0.17[i]
Roundy et al. 1978	Cold desert (Great Basin, Nevada) – woodland	Shrub canopy area (*A. tridentata*)	Unb	9	5	-	3.3/60	Artificial	-	Dry	17	-	83	3.08	-	0.18
		Interspace	Unb	9	5	-	3.3/60	Artificial	-	Dry	-	-	-	2.27	-	0.42
		Tree canopy area (*P. monophylla or J. osteosperma*)	Unb	9	5	-	3.3/60	Artificial	Rep.	Dry	1	-	99	3.28	-	0.02
		Shrub canopy area (*A. tridentata*)	Burn	9	5	1–2	3.3/60	Artificial	-	Dry	80	-	20	3.06	-	0.28
		Interspace	Burn	9	5	1–2	3.3/60	Artificial	-	Dry	-	-	-	2.34	-	0.3
		Tree canopy area (*P. monophylla or J. osteosperma*)	Burn	9	5	1–2	3.3/60	Artificial	Rep.	Dry	25	-	75	3.2	-	0.08
		Shrub canopy area (*A. tridentata*)	Unb	9	5	-	3.3/60	Artificial	-	Wet	17	-	83	2.85	-	0.26
		Interspace	Unb	9	5	-	3.3/60	Artificial	-	Wet	-	-	-	1.48	-	0.38
		Tree canopy area (*P. monophylla or J. osteosperma*)	Unb	9	5	-	3.3/60	Artificial	Rep.	Wet	1	-	99	3.25	-	0.02
		Shrub canopy area (A. tridentata)	Burn	9	5	1–2	3.3/60	Artificial	-	Wet	80	-	20	2.48	-	0.47
		Interspace	Burn	9	5	1–2	3.3/60	Artificial	-	Wet	-	-	-	1.29	-	0.39
		Tree canopy area (*P. monophylla or J. osteosperma*)	Burn	9	5	1–2	3.3/60	Artificial	Rep.	Wet	25	-	75	2.94	-	0.09

(Continued)

Table 4-2—(Continued).

Study	Region (location) - community type	Microsite (plant)	Treatment /burn severity	Plot size (ft^2)	Slope (%)	Time since trmt. (mth)	Rain rate (in h^{-1}) /duration (min)	Rain type	WDPT (s)[a]	Soil water (%)[b] /conditions	Bare soil (%)	Canopy cover (%)	Ground cover (%)	Avg. Infiltration (in h-1)	Runoff coef. (%)[c]	Sed. yield (t ac^{-1})
Roundy et al. 1978 *continued*	Cold desert (Great Basin, Nevada) – woodland *continued*	Shrub canopy area (*A. tridentata*)	Unb	9	8	-	3.3/60	Artificial	-	Dry	10	-	90	3.16	-	0.24
		Interspace	Unb	9	8	-	3.3/60	Artificial	-	Dry	-	-	-	1.62	-	0.65
		Tree canopy area (*P. monophylla or J. osteosperma*)	Unb	9	8	-	3.3/60	Artificial	Rep.	Dry	1	-	99	3.26	-	0.05
		Shrub canopy area (*A. tridentata*)	Burn	9	8	1–2	3.3/60	Artificial	-	Dry	45	-	55	3.14	-	0.35
		Interspace	Burn	9	8	1–2	3.3/60	Artificial	-	Dry	-	-	-	1.52	-	0.47
		Tree canopy area (*P. monophylla or J. osteosperma*)	Burn	9	8	1–2	3.3/60	Artificial	Rep.	Dry	19	-	81	3.09	-	0.17
		Shrub canopy area (*A. tridentata*)	Unb	9	8	-	3.3/60	Artificial	-	Wet	10	-	90	2.92	-	0.36
		Interspace	Unb	9	8	-	3.3/60	Artificial	-	Wet	-	-	-	0.77	-	0.81
		Tree canopy area (*P. monophylla or J. osteosperma*)	Unb	9	8	-	3.3/60	Artificial	Rep.	Wet	1	-	99	3.24	-	0.04
		Shrub canopy area (*A. tridentata*)	Burn	9	8	1–2	3.3/60	Artificial	-	Wet	45	-	55	2.68	-	0.49
		Interspace	Burn	9	8	1–2	3.3/60	Artificial	-	Wet	-	-	-	0.99	-	0.98
		Tree canopy area (*P. monophylla or J. osteosperma*)	Burn	9	8	1–2	3.3/60	Artificial	Rep.	Wet	19	-	81	3.09	-	0.27
Pierson et al. 2007	Cold desert (Great Basin, Oregon) woodland	Intercanopy	None	350	19	-	2.2/60	Artificial	-	Wet	84	6	16	-	25	0.53
		Intercanopy – trees removed[d]	Cut	350	19	-	2.2/60	Artificial	-	Wet	64	23	36	-	2	~ 0.01
Pierson et al. 2009	Cold desert (Great Basin, Idaho) shrubland-woodland	Shrub canopy area (*A. tridentata*)	Unb	5	35-50	1	3.3/60	Artificial	286	7	2	84	98	-	39	0.08
			Mod-High	5	35-50	1	3.3/60	Artificial	261	3	42	10	58	-	76	0.82
		Interspace	Unb	5	35-50	1	3.3/60	Artificial	110	3	25	31	75	-	63	0.87
			Mod-High	5	35-50	1	3.3/60	Artificial	117	4	84	0	16	-	55	3.15
Pierson et al. 2009	Cold desert (Great Basin, Idaho) shrubland-woodland	Intercanopy	Unb	350	35-50	1	3.3/60	Artificial	-	2	24	57	76	-	4	0.04
			Mod-High	350	35-50	1	3.3/60	Artificial	208	4	76	0	24	-	27	4.41

(Continued)

Table 4-2—(Continued).

Study	Region (location) - community type	Microsite (plant)	Treatment /burn severity	Plot size (ft^2)	Slope (%)	Time since trmt. (mth)	Rain rate (in h^{-1}) /duration (min)	Rain type	WDPT (s)[a]	Soil water (%)[b] /conditions	Bare soil (%)	Canopy cover (%)	Ground cover (%)	Avg. Infiltration (in h-1)	Runoff coef. (%)[c]	Sed. yield (t ac^{-1})
Pierson et al. 2013; Williams et al. 2014a	Cold desert (Great Basin, Idaho) woodland	Shrub canopy area (*Artemisia* spp.)	Unb	5	20	-	4.0/45	Artificial	< 5	Wet	25	117	75	2.72	20	0.03
			High	5	18	11	4.0/45	Artificial	11	Wet	57	21	43	2.83	23	0.64
		Interspace	Unb	5	14	-	4.0/45	Artificial	< 5	Wet	46[k]	20	54	1.5	63	0.16
			High	5	16	11	4.0/45	Artificial	< 5	Wet	49[k]	21	51	1.97	51	0.6
		Tree canopy area[l] (*J. occidentalis*)	Unb	5	21	-	4.0/45	Artificial	42	Wet	0	17[l]	100	3.03	23	0.03
			High	5	17	11	4.0/45	Artificial	54	Wet	50	5[l]	50	1.69	58	0.92
		Intercanopy	Unb	140	19	-	4.0/45	Artificial	-	Wet	28[m]	18	72	2.28	50	1.21
			High	140	16	11	4.0/45	Artificial	-	Wet	39[m]	32	61	2.28	50	2.55
		Tree canopy area[l] (*J. occidentalis*)	Unb	140	16	-	4.0/45	Artificial	Rep.	Wet	7	26[l]	93	4.17	13	0.21
			High	140	18	11	4.0/45	Artificial	Rep.	Wet	25	15[l]	75	1.85	58	4.83
Pierson et al. 2010, 2015	Cold desert (Great Basin, Nevada) - woodland	Intercanopy	Unb	140	9	-	2.5/45	Artificial	-	6	26[n]	39	74	1.81	24	0.2
			High	140	9	10	2.5/45	Artificial	-	1	70[n]	23	30	2.37	6	0.11
		Tree canopy area (*P. monophylla or J.osteosperma*)[l]	Unb	140	9	-	2.5/45	Artificial	Rep.	11	3	27[l]	97	2.09	3	0.08
			High	140	9	10	2.5/45	Artificial	Rep.	2	19	6[l]	81	2.31	1	0.03
		Intercanopy	Unb	140	9	-	4.0/45	Artificial	-	Wet	26[n]	39	74	2.24	47	0.99
			High	140	9	10	4.0/45	Artificial	-	Wet	70[n]	23	30	2.4	40	1.54
		Tree canopy area (*P. monophylla or J. osteosperma*)[l]	Unb	140	9	-	4.0/45	Artificial	Rep.	Wet	3	27[l]	97	4.02	5	0.16
			High	140	9	10	4.0/45	Artificial	Rep.	Wet	19	6[l]	81	3.61	13	0.35
Pierson et al. 2010, 2015	Cold desert (Great Basin, Utah) - woodland	Intercanopy	Unb	140	14	-	2.5/45	Artificial	-	7	29[o]	19	71	2.28	10	0.17
			High	140	19	10	2.5/45	Artificial	-	7	43[o]	17	57	2.25	6	0.18
		Tree canopy area (*J. osteosperma*)[l]	Unb	140	15	-	2.5/45	Artificial	Rep.	9	8	21[l]	92	2.51	2	0.06
			High	140	19	10	2.5/45	Artificial	Rep.	6	41	3[l]	59	1.95	21	2
		Intercanopy	Unb	140	14	-	4.0/45	Artificial	-	Wet	29[o]	19	71	2.6	44	1.32
			High	140	19	10	4.0/45	Artificial	-	Wet	43[o]	17	57	2.18	41	2.19
		Tree canopy area (*J. osteosperma*)[l]	Unb	140	15	-	4.0/45	Artificial	Rep.	Wet	8	21[l]	92	4.41	10	0.29
			High	140	19	10	4.0/45	Artificial	Rep.	Wet	41	3[l]	59	2.18	52	8.44
Pierson et al. 2014	Cold desert (Great Basin, Nevada) - woodland	Shrub canopy area (*Artemisia* spp.)	Unb	5	11	-	4.0/45	Artificial	< 5	Wet	12	93	88	3.66	4	0.03
			High	5	13	10	4.0/45	Artificial	< 5	Wet	49	53	51	3.19	10	0.21
		Interspace	Unb	5	9	-	4.0/45	Artificial	< 5	Wet	44[p]	33	56	2.36	41	0.1
			High	5	10	10	4.0/45	Artificial	< 5	Wet	49[p]	30	51	2.13	46	0.18
		Tree canopy area (*P. monophylla or J. osteosperma*)	Unb	5	12	-	4.0/45	Artificial	48	Wet	0	7[q]	100	4.02	0	0
			High	5	15	10	4.0/45	Artificial	65	Wet	9	4[q]	91	2.68	28	0.21

(Continued)

Table 4-2—(Continued).

Study	Region (location) - community type	Microsite (plant)	Treatment /burn severity	Plot size (ft^2)	Slope (%)	Time since trmt. (mth)	Rain rate (in h^{-1}) /duration (min)	Rain type	WDPT (s)[a]	Soil water (%)[b] /conditions	Bare soil (%)	Canopy cover (%)	Ground cover (%)	Avg. Infiltration (in h-1)	Runoff coef. (%)[c]	Sed. yield (t ac^{-1})
Pierson et al. 2014	Cold desert (Great Basin, Utah) - woodland	Shrub canopy area (*Artemisia* spp.)	Unb	5	17	-	4.0/45	Artificial	< 5	Wet	18	69	82	3.58	8	0.15
			High	5	16	10	4.0/45	Artificial	< 5	Wet	44	28	56	2.48	29	0.98
		Interspace	Unb	5	19	-	4.0/45	Artificial	< 5	Wet	52[r]	19	48	1.77	56	1.04
			High	5	16	10	4.0/45	Artificial	< 5	Wet	38[r]	7	62	1.46	64	1.57
		Tree canopy area (*J. osteosperma*)	Unb	5	20	-	4.0/45	Artificial	88	Wet	7	22[q]	93	2.76	22	0.44
			High	5	21	10	4.0/45	Artificial	125	Wet	9	2[q]	91	2.99	18	1.31

[a]Water drop penetration time (WDPT) is an indicator of persistence and strength of soil water repellency as follows: < 5 s wettable, 5 to 60 s slightly repellent, 60 to 600 s strongly repellent (Bisdom et al. 1993). "Rep." indicates authors reported water repellent soil conditions but did not specifically provide a WDPT or other quantitative measure of soil water repellency for respective plots.

[b]Measured near the soil surface (< 5 cm depth).

[c]Runoff coefficient is equal to cumulative runoff divided by cumulative rainfall applied. Value is multiplied by 100 to obtain percentage.

[d]Cumulative runoff and sediment yield for period of 1 July 1998 to 1 October 1998 resulting from natural rainfall events (~ 3.9 in). Fire was in May 1998.

[e]Informal water drop tests showed no postfire soil water repellency at soil surface (O'Dea and Guertin 2003).

[f]Cumulative runoff and sediment yield for period of 1 July 1999 to 1 October 1999 resulting from natural rainfall events (4.2 in). Fire was in May 1998.

[g]Data shown are for experiments on initial dry conditions (dry run) at Coyote Butte, Nancy, and Summit sites, respectively, by row.

[h]Data presented from south-facing slopes solely.

[i]Runoff and erosion following natural rainfall events were monitored over a 26-month period.

[j]*J. occidentalis* trees removed from site by chainsaw cutting 10 years before rainfall simulation experiments.

[k]Bare ground was about 90 percent across unburned (42 percent rock and 46 percent bare soil) and burned (43 percent rock and 49 percent bare soil); ground cover column includes rock cover (and ash for burned plots).

[l]Trees removed from plot by chainsaw immediately before simulations.

[m]Bare ground was about 88 percent (60 percent rock and 28 percent bare soil) for unburned and 88 percent (45 percent rock, 4 percent ash, and 39 percent bare soil) for burned; ground cover column includes rock (and ash for burned plots).

[n]Bare ground was about 64 percent (38 percent rock and 26 percent bare soil) for unburned and about 86 percent (16 percent rock, < 1 percent ash, and 70 percent bare soil) for burned; ground cover column includes rock cover (and ash for burned plots).

[o]Bare ground was about 79 percent (50 percent rock and 29 percent bare soil) for unburned and about 81 percent (38 percent rock, < 1 percent ash, and 43 percent bare soil) for burned; ground cover column includes rock cover (and ash for burned plots).

[p]Bare ground was about 73 percent (29 percent cover and 44 percent bare soil) for unburned and 87 percent for burned (38 percent rock and 49 percent bare soil); ground cover column includes rock cover (and ash for burned plots).

[q]Trees removed from plot about 12 months before simulation as part of earlier study (Pierson et al. 2010).

[r]Bare ground ≥ 90 percent across unburned (38 percent rock cover and 52 percent bare soil) and burned (56 percent rock cover and 38 percent bare soil); ground cover column includes rock cover (and ash for burned plots).

The authors found that saturated hydraulic conductivity was statistically similar for undercanopy areas (5.91 in h^{-1}) and intercanopy areas (2.87 in h^{-1}) due to high variability in canopy area values, but that unsaturated conductivities were greater for canopy areas (0.20–1.50 in h^{-1}) than bare interspaces (0.08–0.39 in h^{-1}). Vegetated interspace unsaturated conductivities (0.12–0.71 in h^{-1}) were similar to both canopy areas and bare interspaces. The reported saturated and unsaturated hydraulic conductivities reflect wet and dry conditions, respectively, for the soil surface after removal of litter and duff, but with any soil crust intact.

In a similar infiltrometer (0.63-inch diameter) study on loamy sand soils of Utah juniper-twoneedle pinyon woodlands, Madsen et al. (2008) assessed unsaturated hydraulic conductivities and soil water repellency in litter-covered canopy areas underneath juniper and pinyon and in intercanopy areas with biological soil crusts. The study found soils underneath trees were hydrophobic and yielded an average unsaturated hydraulic conductivity of 0.68 in h^{-1}, with conductivity rates increasing with distance from the base of the tree (0.18–2.26 in h^{-1}). Unsaturated hydraulic conductivity varied substantially for the wettable or hydrophilic soil conditions in the intercanopy (~4.93 in h^{-1}) and was, on average, 3.52 in h^{-1} for a transitional zone between the tree canopy edge and the intercanopy and 5.98 in h^{-1} within the intercanopy beyond this transitional zone. Soil water content averaged 0.08 in^3 in^{-3} in canopy areas, 0.19 in^3 in^{-3} in the intercanopy, and 0.18 in^3 in the intermediate zone between tree canopies and the intercanopy.

As in the Wilcox et al. (2003c) infiltrometer study, litter and duff were removed before the infiltrometer experiments, but biological soil crusts were left in place. The trend of higher infiltration rates in canopy areas versus intercanopy areas in the Wilcox et al. (2003b) study reflect the effect of infiltration-inhibiting vesicular crusting (also see Blackburn 1975; Blackburn and Skau 1974; Pierson et al. 1994; Roundy et al. 1978) in the interspace. However, two other studies in Utah juniper reported greater infiltration in intercanopy than in canopy areas resulting from the effect of soil water repellency on infiltration into mineral soils beneath trees (Lebron et al. 2007; Madsen et al. 2008). Lebron et al. (2007) pointed out that the unsaturated infiltrometer experiments in the Wilcox et al. (2003c) study were conducted on wet soils immediately after the saturated infiltrometer experiments in that study and therefore may not capture the effect of soil water repellency on infiltration. Wilcox et al. (2003c) did not report on presence or absence of soil water repellency, but, as also noted by Lebron et al. (2007), soil water repellency is more the norm than exception under litter layers of juniper and pinyon trees (fig. 4-7; Madsen et al. 2008, 2011; Pierson et al. 2010, 2013, 2014; Williams et al. 2014a, 2016a, 2019). Neither the Lebron et al. (2007) nor Madsen et al. (2008) studies reflect the influences of interception and water storage by the canopy and litter layers in buffering soil water repellency effects on infiltration and runoff generation (Meeuwig 1971; Pierson et al. 2008a, 2009, 2010, 2013, 2014, 2015; Williams et al. 2014a, 2016a, 2019).

A number of rainfall simulation studies have provided infiltration estimates across diverse woodland conditions and demonstrate the partitioning effect of vegetation and groundcover on water availability for runoff on woodlands (table 4-2). Blackburn and Skau (1974) reported infiltration rates ranging 1.97–2.85 in h^{-1} for initially dry soil conditions and 1.71–2.79 in h^{-1} for initially wet soil conditions across singleleaf pinyon-Utah juniper and Utah juniper woodlands in Nevada. The rainfall application rate was 3.0 in h^{-1} over a 30-minute duration over a variety of plot sizes—spanning canopy and interspace areas—with most being 3 feet by 3 feet in size (Blackburn and Skau 1974).

Roundy et al. (1978) assessed infiltration into soils derived from volcanic parent material on alluvial fans with 5–8 percent slopes (table 4-2). The sites were dominated by singleleaf pinyon and Utah juniper. Rainfall was applied at a rate of 3.31 in h^{-1} for one

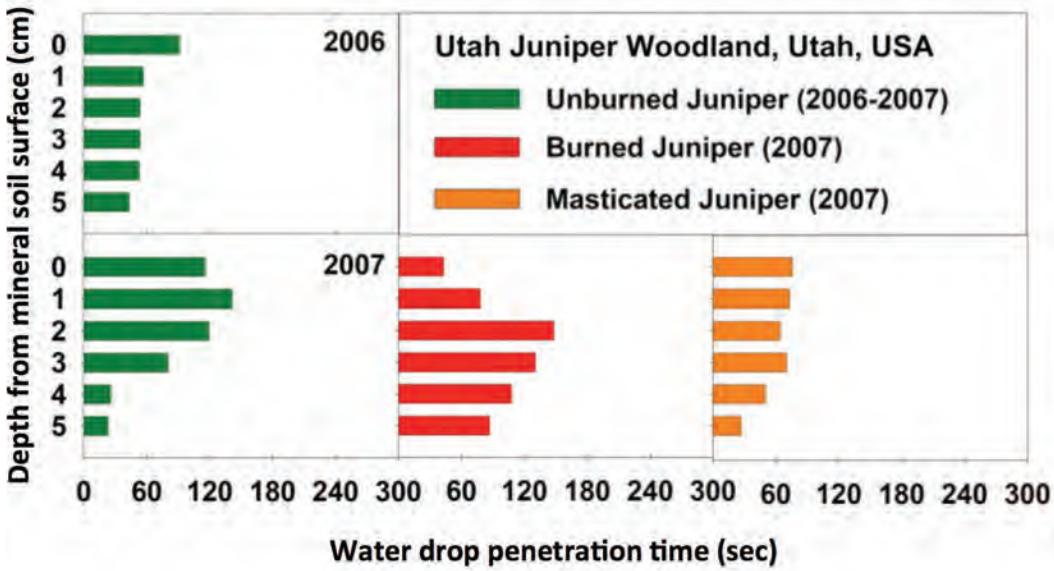

Figure 4-7—Persistence of soil water repellency in tree canopy areas of unburned, burned, and masticated Utah juniper as measured by the water drop penetration time (WDPT; Bisdom et al. 1993). Data from Pierson et al. (2010, 2014). Depth from mineral surface shown in cm (1 in = 2.54 cm), as presented by Pierson et al. (2010, 2014). Soils are water repellent where WDPT ≥ 5 s.

hour to plots approximately 3 feet by 3 feet in size and to variable-sized plots at dry and wet antecedent moisture conditions. Infiltration rates were generally similar for dry and wet soil conditions across tree canopy areas (3.27 in h^{-1}) and shrub canopy areas (2.99 in h^{-1}) respectively, but were substantially lower for interspaces under dry (1.93 in h^{-1}) and wet soil conditions (1.14 in h^{-1}) with respect to all canopy areas.

In a multi-year series of studies on singleleaf pinyon-Utah juniper, Utah juniper, and western juniper woodlands, Pierson et al. (2010, 2013, 2014) and Williams et al. (2014a, 2019) reported average infiltration rates under initially dry soil conditions ranging from 1.06–1.97 in h^{-1} for interspaces, 1.78–2.52 in h^{-1} for tree canopy areas, and 2.40–2.52 in h^{-1} for sagebrush canopy areas (table 4-2). The same studies reported average infiltration rates under initially wet soil conditions ranging from 1.06–2.36 in h^{-1} for interspaces, 2.68–4.02 in h^{-1} for tree canopy areas, and 2.72–4.02 in h^{-1} for sagebrush canopy areas. Rainfall was applied at 2.52 in h^{-1} for 45 minutes for the dry soil conditions and 4.02 in h^{-1} for 45 minutes for the wet soil conditions and plot sizes were approximately 5.4 ft^2. Soils in the Pierson et al. (2010, 2013, 2014) and Williams et al. (2014a, 2019) studies were strongly water repellent underneath pinyon and juniper trees and were wettable in interspaces and underneath shrub canopies.

In a companion study to Pierson et al. (2010, 2013, 2014) and Williams et al. (2014a, 2019), Cline et al. (2010) reported minimum and steady state infiltration rates were nearly threefold greater for vegetated (48 percent foliar cover) versus bare (3 percent foliar cover) interspace plots (approximately 5.4 ft^2), with rainfall applied on wet soil conditions at a rate of 4.02 in h^{-1} for 45 minutes. The above cited studies reflect the generally greater infiltration rates on litter-covered soils underneath trees relative to interspace soils on pinyon and juniper woodlands (table 4-2; fig. 4-6) and demonstrate the effect of the litter layer on buffering strong soil water repellency at the mineral soil surface underneath pinyon and juniper conifers. Likewise, the studies demonstrate that infiltration rates on woodlands decline with reduction of vegetation and groundcover, as reflected by the generally higher infiltration rates in canopy areas and vegetated interspaces relative to bare interspace areas (table 4-2).

This assertion is further supported by a rainfall simulation study by Petersen and Stringham (2008) on western juniper sites in Oregon. The study applied 4.02 in h^{-1} rainfall for 60 minutes under dry antecedent soil conditions to approximately ~2.7 ft^2 intercanopy plots on hillslopes with high (greater than 22 percent), moderate (13–16 percent), and low (less than 3 percent) juniper cover. Steady state infiltration for the low juniper cover hillslopes (3.54 in h^{-1}) was 34 percent and 68 percent greater, respectively, than measured on the moderate (2.36 in h^{-1}) and high (1.14 in h^{-1}) juniper cover hillslopes (Petersen and Stringham 2008). The combination of bare soil and rock cover in the study averaged 23 percent for low juniper cover, 63 percent for the moderate juniper cover, and 94 percent for the high juniper cover plots.

The studies herein clearly demonstrate water available for runoff processes on woodlands is concentrated primarily in the intercanopy between trees and is likely greatest in bare interspace areas. The infiltration rates presented above are likely largely affected by the rainfall application rates and durations, which vary within natural storms, but provide a basis for understanding the distribution of sink and source areas and the potential for runoff generation on woodlands.

Runoff From Woodlands

Plot-scale studies have demonstrated that the amount and type of runoff, as well as the connectedness of runoff sources, along a woodland hillslope are largely determined by magnitude of water input and the amount and continuity of bare ground (fig. 4-1a, 4-8; Pierson et al. 2007, 2010, 2013, 2015; Reid et al. 1999; Roundy et al. 2017; Wilcox et al. 1996a, 2003a; Williams et al. 2014a,b, 2016a,b, 2019). Table 4-2 summarizes results from rainfall experiments across the Intermountain West. Runoff from tree canopy

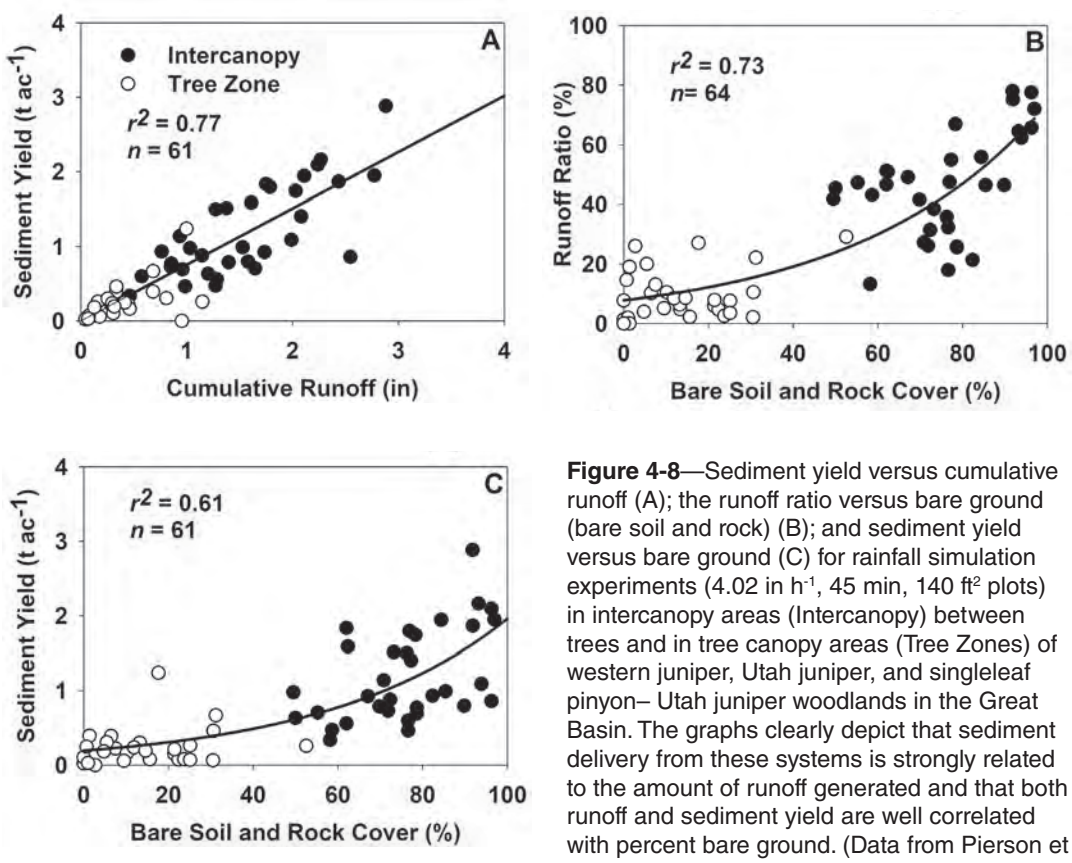

Figure 4-8—Sediment yield versus cumulative runoff (A); the runoff ratio versus bare ground (bare soil and rock) (B); and sediment yield versus bare ground (C) for rainfall simulation experiments (4.02 in h^{-1}, 45 min, 140 ft^2 plots) in intercanopy areas (Intercanopy) between trees and in tree canopy areas (Tree Zones) of western juniper, Utah juniper, and singleleaf pinyon– Utah juniper woodlands in the Great Basin. The graphs clearly depict that sediment delivery from these systems is strongly related to the amount of runoff generated and that both runoff and sediment yield are well correlated with percent bare ground. (Data from Pierson et al. 2010, 2013 and Williams et al. 2014a; figure modified from Williams et al. 2018b.)

areas in pinyon and juniper woodlands is often limited relative to that of the intercanopy between trees due to precipitation interception and water storage in the canopy and litter layers (table 4-2; fig. 4-8; Pierson et al. 2010, 2013, 2014, 2015; Reid et al. 1999; Wilcox et al. 2003a; Williams et al. 2014a;). In contrast, runoff generated in bare interspaces on woodlands is the primary source for runoff accumulation downslope unless captured by nearby vegetated or litter-covered patches (Davenport et al. 1998; Ludwig et al. 2005; Pierson et al. 2007, 2010, 2013; Reid et al. 1999; Wilcox et al. 2003a; Williams et al. 2014a, 2016a, 2019).

Wilcox (1994) found that 10–18 percent of the annual water budget over a 2-year period was converted to runoff, mostly during intense convective thunderstorms, in the intercanopy (approximately 325 ft^2 plots) of a gently sloping (5 percent) pinyon and juniper woodland in New Mexico. Wilcox (1994) also noted that both winter snowmelt and rain-on-snow events can generate runoff in pinyon and juniper woodlands, but that hillslope runoff risk is likely greatest during high intensity convective storms. Pierson et al. (2010) found that runoff from bare interspace areas on relatively large rainfall simulation plots within the intercanopy at 2 sloping (10–15 percent) Great Basin woodland sites contributed substantially to the formation of concentrated flow during high intensity rainfall application (4.02 in h^{-1}, 45 min; fig. 4-1b). The study found that cumulative runoff from the same simulated storm on small interspace plots was similar to the cumulative runoff measured on the large intercanopy plots, but that the runoff on the larger plots occurred mainly as high velocity concentrated overland flow.

Similar results were reported by Pierson et al. (2013) and Williams et al. (2014a) for a sloping (10–25 percent) western juniper woodland in which the same methodologies as Pierson et al. (2010) were applied. Collectively, the studies found that intercanopy runoff from applied high intensity storms was largely controlled by the combined amount of bare ground (bare soil and rock, averaged 64–89 percent) and increased where bare ground exceeded 50–60 percent (fig. 4-8). Pierson et al. (2010, 2013) and Williams et al. (2014a) measured mean intercanopy runoff rates of 0.28–0.55 in h^{-1} for 2.52 in h^{-1} rainfall intensity on dry soils and 1.97–2.20 in h^{-1} for 4.02 in h^{-1} rainfall intensity applied on wet soils over a 45-minute duration to the 140 ft^2 plots (table 4-2). In another rainfall simulation study, Pierson et al. (2007) found that large patches of bare interspace (averaged 91 percent bare ground) on approximately 350 ft^2 intercanopy plots within a sloping (19 percent) western juniper woodland facilitated formation of concentrated overland flow during 2.17 in h^{-1} applied rainfall over 60-minute duration (table 4-2). Runoff averaged approximately 0, 0.12, 0.20, 0.31, and 0.51 in h^{-1} at 5, 10, 15, 30, and 60-minutes into the simulations, representative of 2-, 4-, 8-, 50-, and 100-year storm events, respectively (Pierson et al. 2007).

Reid et al. (1999) measured seasonal runoff from natural rainfall in intercanopy and canopy areas of a sloping (approximately 10 percent) twoneedle pinyon-oneseed juniper woodland over a 26-month period (table 4-2). That study found that a substantial portion (37 percent) of the precipitation from rainfall events was converted to runoff in bare intercanopy patches and that 12 percent of the precipitation from these areas was recaptured as run-on in vegetated intercanopy patches downslope. Reid et al. (1999) estimated that tree canopy patches covered 50 percent of their study site and described intercanopy areas as a mosaic of patches devoid of vegetation and patches with relatively dense vegetation. The authors further noted that bare patch connectivity was limited at the site and that there was little indication of rilling (Reid et al. 1999).

Studies discussed above (Pierson et al. 2007, 2010, 2013; Reid et al. 1999; Williams et al. 2014a) contrast two different woodland intercanopy areas that function very differently hydrologically. Studies by Pierson and Williams document runoff responses for woodlands with extensive, well-connected intercanopy bare ground and high runoff—

and the third study by Reid documents substantial capture of runoff as run-on in an intercanopy with limited bare ground connectivity. Similar contrasting responses across multiple sites led Wilcox et al. (2003a) to characterize woodlands such as in the Pierson et al. (2007, 2010, 2013) and Williams et al. (2014a) studies with extensive bare ground connectivity and high runoff rates as "nonconserving" or "leaky" and those as in the Reid et al. (1999) study with patchy bare ground as "resource conserving." Suffice to say that woodlands of the Great Basin and Colorado Plateau exist across both conditions and therefore hillslope runoff behavior is quite variable across this vast domain. However, the general nonlinear trend of increasing patch-scale to hillslope runoff contributions with increasing bare ground and bare intercanopy connectivity is likely common for runoff generating storms on these landscapes (Davenport et al. 1998; Pierson et al. 2010, 2011, 2013; Urgeghe et al. 2010; Wilcox et al. 1996a, 2003a; Williams et al. 2014a,b).

Watershed scale studies on runoff from pinyon and juniper woodlands are more limited than plot-scale to hillslope scale studies. Wilcox (1994) provides a summary of numerous early (1960–1980 era) watershed scale (approximately 60 to more than 150,000 acres) runoff studies for southwestern U.S. pinyon and juniper woodlands with winter- and summer-dominated precipitation regimes. The summary reports that although runoff ranged from 2–23 percent of the annual water budget (11–21 inches) for the studies reviewed, runoff from southwestern U.S. pinyon and juniper woodlands generally amounts to less than 10 percent of the annual water budget (Wilcox 1994). Wilcox (1994) further noted that evapotranspiration is the dominant water loss mechanism on southwestern U.S. pinyon and juniper woodlands (fig. 4-9); that streamflow from these woodlands is typically ephemeral at the annual time scale; and that the seasonality of runoff for these landscapes is strongly related to the precipitation regime, with winter flows more common on snowy uplands and high summer flows occurring following intense thunderstorms.

More recently, Kormos et al. (2017b) summarized hydrologic data collected over a period of 6 years for 4 western juniper dominated (42–61 percent juniper canopy cover) experimental watersheds in southwestern Idaho. The watersheds range in size from

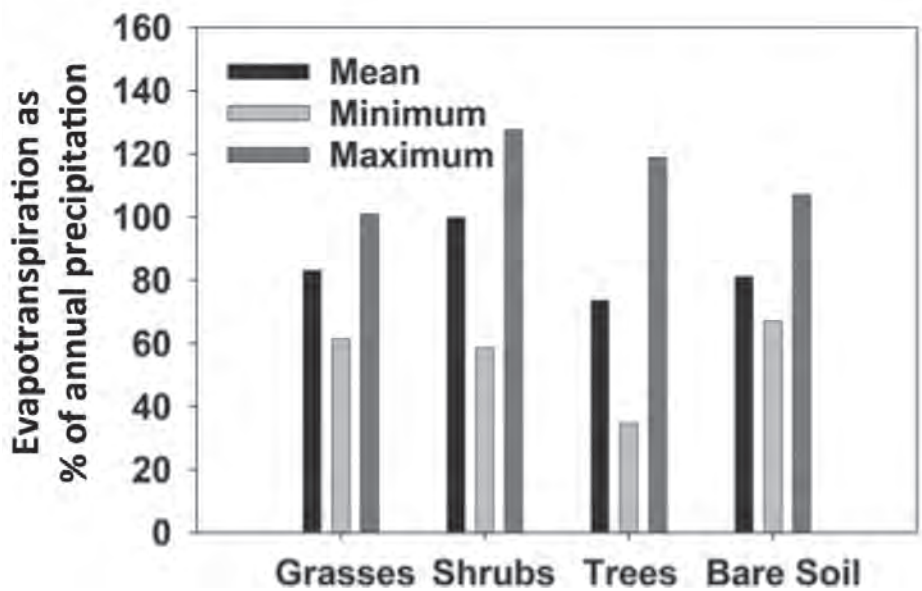

Figure 4-9—Estimated averages and ranges (as maximum and minimum) of annual evapotranspiration as a percentage of annual precipitation for rangeland plant types as estimated from the literature and reported in Pierson and Williams 2016.

approximately 50–175 acres and span hillslope gradients of approximately 20 percent. Annual precipitation at the sites (around 25 inches) occurs primarily during the winter and spring seasons and is therefore dominated (53–76 percent) by snowfall and mixed-phase events typical of inland northwest woodlands (Kormos et al. 2017b). Streamflow at the sites is ephemeral in response to snowmelt and rain-on-snow events, usually ceasing in late spring to mid-summer (Kormos et al. 2017b). Average annual streamflow across the four watersheds for the period of record was approximately 4.5 inches, or about 18 percent of the mean annual precipitation for the same period (Kormos et al. 2017b). Collectively, the Wilcox (1994) and Kormos et al. (2017b) studies characterize watershed scale runoff responses common to woodlands at the annual time scale spanning the rain-dominated, mixed-phase, and snow-dominated precipitation regimes in which pinyon and juniper woodlands occur (Caroll et al. 2016; Deboodt 2008; Kormos et al. 2017a,b; Niemeyer et al. 2017; Ochoa et al. 2018; Wilcox et al. 2003a). Although streamflow amounts to only a small portion of the annual water budget for these systems, the patchy structure of pinyon and juniper woodlands, particularly where degraded, exhibit limited buffering capacity to the most intense storms and can be subject to extreme runoff events (fig. 4-10a,b; Roundy and Vernon 1999).

Erosion From Woodlands

Rainfall simulation experiments provide reasonable estimates of pinyon and juniper woodland splash-sheet erosion (see Glossary for rainsplash and sheet erosion) occurring over fine spatial scales (table 4-2). Blackburn and Skau (1974) applied rainfall at 3 in h^{-1} over a 30-minute duration to a variety of plot sizes spanning canopy and interspace areas in pinyon and juniper woodlands in Nevada. They reported sediment yields ranging 0–0.42 t ac^{-1} for initially dry soil conditions and 0–0.62 t ac^{-1} for initially wet soil conditions across a diversity of soils. In another singleleaf pinyon-Utah juniper study, Roundy et al. (1978) found splash-sheet erosion from volcanic soils was substantially higher for interspaces (0.38–0.81 t ac^{-1}) relative to shrub canopy areas (0.18–0.36 t ac^{-1}) and tree canopy areas (0.02–0.05 t ac^{-1}) during 3.31 in h^{-1} rainfall simulations applied for one hour across dry and wet antecedent moisture conditions (table 4-2).

Rainfall simulation studies by Pierson et al. (2010, 2013, 2014) and Williams et al. (2014a, 2019) likewise reported higher splash-sheet erosion levels for interspaces than shrub and tree canopy areas across multiple sloping (10–25 percent) pinyon and juniper

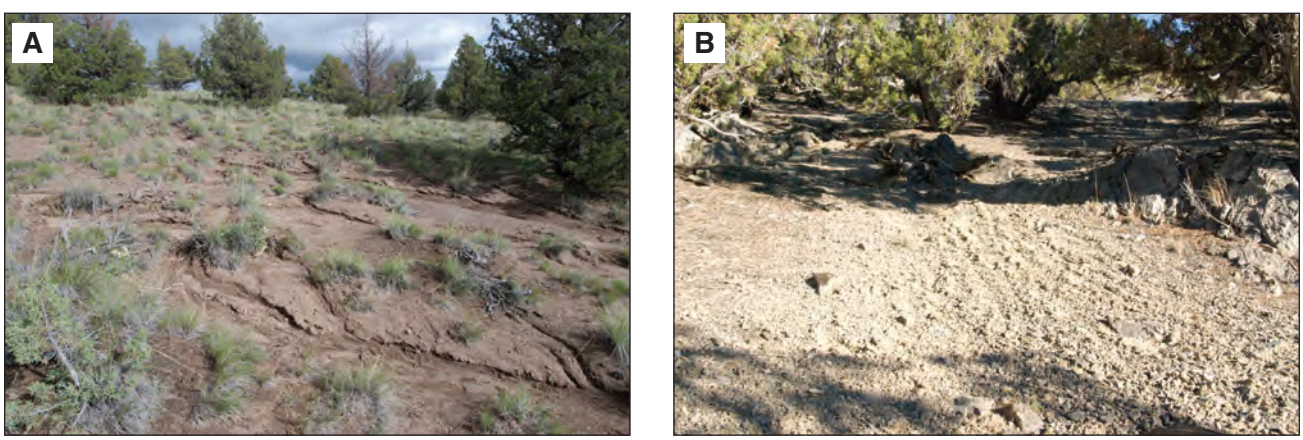

Figure 4-10—Sediment delivery on pinyon and juniper woodlands during runoff generating storms is largely controlled by the amount and intensity of precipitation and connectivity of bare intercanopy areas. (A) Although the understory vegetation is intact, a high-intensity storm still resulted in some soil loss and development of rills. (B) Increased connectivity of bare ground, especially where it exceeds 50 percent, results in high runoff and sediment loss. Some sites have lost the A horizon. Central Nevada. (Photos by Rick Miller, Oregon State University.)

woodlands sites in the Great Basin spanning soils from volcanic to sedimentary parent rocks (table 4-2). The studies applied rainfall rates on 5.4 ft^2 plots at 2.52 in h^{-1} for 45 minutes for dry soil conditions and 4.02 in h^{-1} for 45 minutes for the wet soil conditions. The authors reported average sediment yields for initially dry soil conditions ranging from 0.03 to 0.56 t ac^{-1} for interspaces, 0–0.24 t ac^{-1} for tree canopy areas, and 0–0.04 t ac^{-1} for sagebrush canopy areas.

The same studies reported sediment yields for initially wet soil conditions ranging from 0.16 to 1.70 t ac^{-1} for interspaces, 0–0.78 t ac^{-1} for tree canopy areas, and 0–0.21 t ac^{-1} for sagebrush canopy areas. The wide range in values for a given microsite (interspace, tree canopy, shrub canopy) and soil moisture condition (dry, wet) reflect different soil erodibilities across the study sites associated with the varying soil types, with soils derived of sedimentary rock (limestone and sandstone) having the highest erodibility (Pierson et al. 2010). The generally higher sediment yields from interspaces are due to higher bare soil exposure and runoff for interspace areas relative to the tree and shrub canopy areas (Pierson et al. 2010, 2013, 2014; Williams et al. 2014a, 2019). A western juniper woodland study by Petersen and Stringham (2008) provided limited specific data on sediment yields from intercanopy rainfall simulations on hillslopes representing a gradient of juniper dominance and bare conditions. That study found that 1-hour rainfall simulations on 2.7 ft^2 intercanopy plots at a 4.02 in h^{-1} intensity produced threefold more sediment from bare intercanopy plots (4.49 t ac^{-1}) than vegetated intercanopy plots (1.33 t ac^{-1}) on soils derived from volcanic parent rock.

Cline et al. (2010), using the same methodologies as described for Pierson et al. (2010) above, also reported a two- to threefold greater sediment yield for 2.52 in h^{-1} and 4.02 in h^{-1} rainfall simulations from bare (0.28 and 1.39 t ac^{-1}) than vegetated interspaces (0.07 and 0.59 t ac^{-1}) at Utah juniper woodland. The studies cited above clearly depict the typical distribution of sediment sources on pinyon and juniper woodlands, with sediment primarily generated from bare and vegetated interspaces and overall erodibility varying with soil type (Al-Hamdan et al. 2012b; Cline et al. 2010; Pierson et al. 2010, 2011; Roundy et al. 1978; Williams et al., 2014a, 2014b, 2016a, 2019).

Findings from plot-scale studies underscore that the potential for cross-scale sediment delivery on pinyon and juniper woodlands during runoff generating storms is largely controlled by the amount and connectivity of bare intercanopy area (table 4-2, fig. 4-8; Pierson et al. 2007, 2010, 2013, 2015; Reid et al. 1999; Wilcox et al. 2003a; Williams et al. 2014a, 2016a, 2019). As previously discussed, interspaces on woodlands are the primary sources for runoff and sediment, and, where well connected, these sources accumulate in concentrated flow paths (figs. 4-1b, 4-3) with high flow velocity, erosive energy, and sediment transport capacity (Al-Hamdan et al. 2012a, 2012b, 2013; Nouwakpo et al. 2016; Pierson et al. 2007, 2010; Williams et al. 2014a, 2016a, 2019).

Pierson et al. (2007, table 4-2) reported sediment yields of approximately 0, 0.02, 0.04, 0.13, and 0.52 t ac^{-1} at 5, 10, 15, 30, and 60 minutes (respectively) into rainfall simulations on approximately 350 ft^2 intercanopy plots at an application rate of 2.13 in h^{-1} in a western juniper study. The authors found that runoff from bare interspaces during concentrated flow experiments facilitated high flow velocities (approximately 0.33 foot s^{-1}) and sediment concentrations (approximately 2,200-2,600 ppm).

Similar studies of Utah juniper, singleleaf-Utah juniper, and western juniper woodlands by Pierson et al. (2010, 2013, 2015) and Williams et al. (2014a, 2016a) found intercanopy sediment yield from high intensity rainfall simulations (140 ft^2 plots) increased nonlinearly with bare ground where bare ground exceeded 50–60 percent due to formation of high velocity concentrated flow paths. Those studies reported intercanopy flow velocities ranging 0.20 to 0.66 ft s^{-1} for concentrated flow experiments with flow

releases of approximately 4, 8, and 12 gal min^{-1}. High runoff rates on intercanopy plots during rainfall simulation experiments in the study transported interspace generated sediment downslope in concentrated flow resulting in cumulative sediment yields ranging 0.16–0.20 t ac^{-1} and 0.99–1.79 t ac^{-1} for simulations at 2.52 in h^{-1} (dry conditions) and 4.02 in h^{-1} (wet conditions) intensities, 45-minute durations (Pierson et al. 2010, 2013, 2015; Williams et al. 2014a, 2016a).

In contrast, concentrated flow paths were limited on litter-covered tree canopy areas and sediment yield from the same simulations on these plots ranged 0.04–0.08 t ac^{-1} and 0.16–0.35 t ac^{-1} for the lower and higher intensity rates, respectively (Pierson et al. 2010, 2013, 2015; Williams et al. 2014a, 2016a). The Pierson et al. (2010, 2013) and Williams et al. (2014a, 2016a) studies found that intercanopy sediment yield increased with increase plot scale (from 5.4 ft^2–140 ft^2) even though runoff rates were similar across plot scales. The authors attributed the increased sediment delivery across spatial scales within the intercanopy to the concentration of overland flow at the larger plot scale, indicative of a "nonconserving" system as described for degraded woodlands in the southwestern United States (Davenport et al. 1998; Wilcox et al. 1996a, 2003a). Reid et al. (1999) and Wilcox et al. (2003a) describe conditions measured in "resource-conserving" woodlands whereby isolated runoff from bare patches is captured in downslope vegetated patches and hillslope sediment loss is limited.

Wilcox (1994) found that erosion from pinyon and juniper woodlands in the southwestern United States is generally higher in the summer in association with high intensity monsoonal thunderstorm events relative to the winter-season runoff from snowmelt with no raindrop impact. That study reported summer season sediment yields of approximately 0.01–1.28 t ac^{-1} and winter-season sediment yields of approximately 0.01–0.05 t ac^{-1} for approximately 325 ft^2 natural runoff plots (5 percent slope, 15 percent bare ground, undisturbed plots only) over a 2-year period (Wilcox 1994). Annual watershed scale erosion estimates for pinyon and juniper woodlands are largely absent from the literature and can vary greatly with land use and disturbance, topography, and soil type (0.08–4.46 t ac^{-1}; see Ffolliott and Gottfried 2012; Hastings et al. 2003; McAuliffe et al. 2014; Wilcox et al. 1996a, 1996b, 2003a), so current estimates are heavily biased by a few studies. Overall, hillslope contributions of sediment to channels and the watershed scale are dictated by the runoff and sediment source and sink structure and are greatest for high magnitude runoff events on sites with well-connected bare intercanopy area (50–60 percent bare ground) and an ample sediment supply (Davenport et al. 1998; Pierson et al. 2011; Wilcox 1994; Wilcox et al. 1996a, 1996b, 2003a; Williams et al. 2014a,b, 2016a).

Soil Water

Vegetation structure affects soil water availability by influencing soil water capture and moderating the soil microclimate through shading from solar radiation and insulating surface soils (Breshears et al. 1997a, 1997b, 1998; Lebron et al. 2007; Pierson and Wight 1991). For example, Pierson and Wight (1991) reported interspace locations in a sagebrush community had higher (by 41.4 ˚F) maximum and lower (by 34.7 ˚F) minimum near-surface (0 to 4-inch depth) soil temperatures than canopy locations during the spring season. Small grass and moss clumps within interspaces had little influence on near-surface soil temperatures, but shrub cover and the associated litter mounds insulated the soil surface from incoming solar radiation during daylight hours and from sensible heat loss at night (Pierson and Wight 1991).

Breshears et al. (1997a) found that interspaces between tree canopies of a twoneedle pinyon-oneseed juniper woodland exhibited greater (40–50 percent more) near-surface

solar radiation than tree canopies, and that preferential shading on the northern side of tree canopy areas significantly reduced near-surface solar radiation. Breshears et al. (1997a) also determined that snow water equivalent was greater in interspace locations than under tree canopies and that the differential accumulation resulted in temporal variability in the spatial arrangement of soil water. Soils in tree canopy areas were wetter than interspace soils in early winter following complete melt of canopy area snowpacks and during the monsoon season immediately after runoff events. Wetter soil conditions on the edges of canopy areas compared to interspaces following monsoon rain events were assumed to be partially related to runoff from interspace locations to canopy areas. Interspace soils were wetter than canopy area soils later in the winter and in early spring during the interspace snowmelt period. The differential snow accumulation and melt patterns, related in large part to canopy snow interception, exerted a greater influence on the spatial distribution of soil water than did the effects of preferential shading (Breshears et al. 1997a). The main effect of solar radiation on soil moisture patterns was observed within interspace patches, where north edges of the intercanopy with greater solar radiation were wetter than the shaded south edges during winter and spring. Breshears et al. (1998), working at the same site as Breshears et al. (1997a), found that maximum air temperature was as much as 50 ˚F greater on interspaces than tree canopy areas during late spring through summer and that the associated differences in spatial temperature produced differences in soil evaporation. The authors suggested that spatial differences in soil temperature affected soil evaporation only when soils were thawed and were amplified at lower soil water contents.

Several authors have postulated that soil water repellency underneath pinyon and juniper canopies may provide water conservation and increased plant productivity for these conifers (Lebron et al. 2007; Madsen et al. 2008; Robinson et al. 2010). Lebron et al. (2007) and Madsen et al. (2008) observed that surface water on water repellent soils under Utah juniper and twoneedle pinyon canopies was routed through the water repellent layer into deeper soil layers via bypass or preferential flow in isolated wet spots. Robinson et al. (2010) likewise found soil water repellency under Utah juniper and twoneedle pinyon concentrated infiltration of summer precipitation to undercanopy soils via preferential flow. Roundy et al. (1978) hypothesized similar behavior to explain rapid infiltration of simulated rainfall into water repellent soils of Utah juniper (table 4-2).

Water availability deep in the soil profile favors woody plant recruitment and increased plant productivity through greater water availability and transpiration rates and recruits surface plant and litter biomass associated with higher infiltration rates (Huxman et al. 2005; Ludwig et al. 2005; Pierson et al. 2010, 2013, 2014, 2015; Wilcox et al. 2003a; Williams et al. 2014a, 2016a,b). Therefore, surface flow routing by soil water repellency may function similar to the lateral surface transfers of overland flow (run-on) in maintaining shrub and woodland tree islands of higher biological activity and water retention (Bhark and Small 2003; Breshears et al. 1997a; Huxman et al. 2005; Ludwig et al. 2005; Reid et al. 1999; Robinson et al. 2010; Schlesinger et al. 1990; Wilcox et al. 2003a). Overall, soil water in pinyon and juniper woodlands is affected by above and belowground physical and biological attributes that regulate spatial variability in water input, storage, and use (Breshears et al. 1997a, 1997b, 1998; Deboodt 2008; Mollnau et al. 2014; Ochoa et al. 2008).

Evapotranspiration

Interception

Plant canopies physically intercept precipitation and the intercepted precipitation is either lost to the atmosphere by evaporation/sublimation or is subsequently transferred to the soil surface as throughfall or stemflow. Interception is strongly influenced by the precipitation intensity, duration, and frequency and by the type and structure of the

vegetative community (Branson et al. 1981; Owens et al. 2006; Dunkerley 2008). The percentage of event gross rainfall captured by cover elements generally decreases as rainfall intensity and duration increases (table 4-3; Branson et al. 1981; Carlyle-Moses 2004; Owens et al. 2006).

Literature on snowfall canopy interception specific to rangeland plants is extremely limited. Hull (1972) and Hull and Klomp (1974) found that dense shrub cover (2.2 plants per 10.8 ft^2) intercepted 37 percent of snowfall at a rangeland site in Idaho. In a twoneedle pinyon-oneseed juniper woodland site in New Mexico, Breshears et al. (1997a) found that snow accumulation during each of three winter seasons was much greater in intercanopy areas between tree canopies than underneath tree canopies. Snow water equivalent in the first year of the 3-year study was about 80 percent greater in the intercanopy openings between trees than in areas underneath canopies. Whole plant interception of wind-distributed snow by rangeland vegetation is paramount in retaining snow against wind scour (Flerchinger and Cooley 2000; Flerchinger et al. 1998; Kormos et al. 2017a; Seyfried and Flerchinger 1994; Seyfried and Wilcox 1995; Marks and Winstral 2001; Marks et al. 2001, 2002; Winstral and Marks 2002). Wind and topography interact to redistribute fallen snow on undulating terrain, while vegetation reduces wind velocities and facilitates deposition (Marks et al. 2001, 2002; Marks and Winstral 2001; Winstral and Marks 2002).

Deeper snow accumulations provide greater insulation for surface soils and plant productivity and prolong snow-covered periods (Liston et al. 2002; Sturm et al. 2001). The vegetation snow-holding capacity is a function of the vegetation height, density of plants, and snowpack conditions (Liston and Sturm 1998; Pomeroy and Gray 1995; Sturm et al. 2001). Hutchinson (1965) found that a shrub stand 20 inches in height stored 1 inch more water than an adjacent area void of shrubs. Flerchinger et al. (1998) reported that snow depth at a wind-driven rangeland site in Idaho typically varied by plant community from less than 24 inches in low sagebrush/grass to 40 inches in mountain big sagebrush-snowberry and 40–315 inches in an aspen-willow stand.

One of the reasons that pinyon and juniper expansion may lead to ecological degradation (Peterson and Stringham 2009) and loss of herbaceous and shrub cover both under tree canopies (Tausch et al. 1981; Miller et al. 2008) and in the intercanopy areas (Bates et al. 2000; Bybee et al. 2016; Davenport et al. 1998) is reduced precipitation inputs due to interception. Savenije (2004) makes a case for interception being the most overlooked component in rainfall and runoff analyses. At the whole tree level, liquid rainfall interception was measured using simulated rainstorms ranging from 0.09 inches–1.02 inches on singleleaf pinyon and Utah juniper (Stringham et al. 2018). Five storms targeting 0.08, 0.20, 0.39, 0.59 and 0.98 in h^{-1} were simulated on 19 individual trees of each species for a total of 130 storms. Actual storm sizes varied somewhat due to wind conditions, so the measured storm sizes were used in the analyses. There was no difference

Table 4-3—Estimated event and annual interception as compiled from the literature and summarized by Pierson and Williams 2016.

Cover type	Event interception as % of gross rainfall	Annual interception as % of gross rainfal
Individual conifer or shrub	50–60 for low intensity	5–50
	5–35 for high intensity	5–15 more common
Litter	2–20	2–20
Shrub or woodland community	5–50	5–25
Herbaceous community	15–80	10–55

in interception based on species, so results were combined for both species. Stringham et al. (2018) found a threshold of 0.20 inches of precipitation; interception was higher for storms of 0.20 inches or less and lower for storms greater than 0.20 inches.

Niemeyer et al. (2016) measured interception of both rain and snow under western juniper instrumented with lysimeters under two tree canopies and two interspaces outside of the canopy were instrumented with lysimeters. The ratio of the interspace to under canopy surface water input was greater for snow (79.4 percent) than for rain (54.8 percent), which was attributed to the redistribution of snow under tree canopies. In other words, a greater fraction of snow made it below the tree canopy while more rainfall was intercepted. In the Great Basin, using rainfall collectors below western juniper tree canopies, 42 percent of annual precipitation was intercepted and subsequently evaporated or sublimated back to the atmosphere (Young et al. 1984). On the Edwards Plateau in Texas, Ashe juniper was monitored with collection tubes under the canopy for 3 years at 10 sites and 2,700 rain events were recorded. Average total interception by tree canopies was 35 percent (Owens et al. 2006). The litter layer under trees can also absorb water that would have otherwise made it to the soil surface. Owens et al. (2006) recorded that on average 5 percent of precipitation is absorbed by the litter layer under Ashe juniper.

Transpiration

Expansion of pinyon and juniper woodlands into areas previously dominated by sagebrush communities introduces deeply rooted evergreen species, which can change the timing and magnitude of transpiration losses relative to shrub and grass dominated communities (Ryel et al. 2010). Pinyon and juniper have different water use strategies as demonstrated by studies at the leaf level through measured photosynthesis, stomatal conductance (in part determines transpiration), and leaf water potentials (a measure of plant water stress) (Angell and Miller 1994; Lajtha and Barnes 1991; Limousin et al. 2013; Williams and Ehleringer 2000). Pinyon is relatively isohydric, which means leaf water potentials are regulated at a fairly conservative minimum stomatal setpoint determined by their vulnerability to xylem cavitation (Meinzer et al. 2009), below which stomata will close and photosynthesis will cease.

Juniper is relatively anisohydric (keeping stomates open for longer periods of time under the presence of decreasing leaf water potentials) and is able to tolerate lower leaf water potentials and keep stomata open, which maintains stomatal conductance and photosynthesis (West et al. 2008). Juniper will therefore continue to transpire water to the atmosphere during drought conditions for a longer time period than pinyon. Minimum leaf water potential demonstrates the divergence in water use strategies of these two species. Minimum leaf water potentials reported for twoneedle pinyon and oneseed juniper in the Southwest and Colorado Plateau range from -2.0 to -2.5 MPa for pinyon and -3.7 to -6.9 MPa for juniper (Lajtha and Barnes 1991; Williams and Ehleringer 2000; Limousin et al. 2013). The ability of oneseed juniper to withstand drought longer than twoneedle pinyon has also been attributed to the ability of juniper to extract water from deeper in the soil profile. Stable isotope ratios in xylem water of these two species show that while both species are able to use summer rain, pinyon is more reliant and responsive to summer rain—which increases shallow soil water—while juniper extracts a greater proportion of water from deeper in the soil profile (Bates et al. 2000; Breshears et al. 1997a; Flanagan et al. 1992; West et al. 2007a,b, 2008).

Williams and Ehleringer (2000) proposed that along the summer monsoon cline (with the largest input of summer rainfall in the Southwest and decreasing monsoon inputs moving northwards) that these species should use more monsoon rainfall in areas where monsoon rainfall is a greater percentage of total rainfall. This idea was largely supported by the authors' findings, but it was a threshold response to a critical amount of

summer precipitation, not a linear response (Williams and Ehleringer 2000). The isotopic evidence contained in 40,000-year-old twoneedle pinyon needles in pack rat middens indicate the distribution of twoneedle pinyon was strongly tied to summer rainfall (Pendall et al. 1999). It is notable that singleleaf pinyon replaces twoneedle pinyon in the Great Basin, which receives less than one-third of its total annual precipitation as summer rain. In primarily winter-spring precipitation regime in the northern Great Basin, transpiration is strongly influenced by soil temperature and moisture availability (Angell and Miller 1994). Peak transpiration occurs during the spring. However, transpiration rates are relatively low compared to other conifers, partially a result of stomata covered by adjacent leaf scales (fig. 2-16a,b; Miller and Shultz 1987).

In a study in southern Utah, twoneedle pinyon and Utah juniper relied on similar shallow water sources in the early spring, and may be in direct competition with understory species. However, during the summer twoneedle pinyon was able to increase transpiration in response to summer rainfall events that created shallow soil water, while Utah juniper does not. Both species are able to obtain a considerable proportion of water from below the shallow soil depth (West et al. 2008) likely due to their ability to grow deep roots into cracks in bedrock and grow on rock outcrops without significant soil development (fig. 4-11; Foxx and Tierney 1987; Harper et al. 2003). In general it appears that twoneedle pinyon is more reliant on summer rainfall than is Utah juniper (Flanagan et al. 1992; Williams and Ehleringer 2000). This requires that twoneedle pinyon maintain active shallow roots, which experience greater temperature extremes that may limit this species in the future if temperatures continue to increase. Evidence for the presence of shallow roots demonstrate twoneedle pinyon can take up water from intercanopy spaces (Breshears et al. 1997b), which could make it competitive with understory shrubs and grasses.

Transpiration can be measured at the whole tree level by installing sensors to measure sap flow rates through xylem tissue (Granier 1987), but scaling such tree level measures

Figure 4-11—Juniper and pinyon roots can go deep into the cracks of bedrock, grow on rock outcrops and exist with very shallow soils (less than 10 inches in depth). Grand Staircase, southern Utah. (Photo by Rick Miller, Oregon State University.)

to the stand level is problematic. Three studies scaled sap flow velocity to the whole stand level using allometric measurements and sap flow rates (Mollnau et al. 2014; Pangle et al. 2015; West et al. 2008). West et al. (2008) measured maximum sap flow rates at 0.01 in d^{-1} and annual total transpiration between 6.5 percent–14.5 percent of total annual rainfall for a site in southern Utah with 9 inches of average annual precipitation. Approximately 88 percent of basal tree cover at the site was oneseed juniper and the remaining 12 percent was twoneedle pinyon (West et al. 2008). Pangle et al. (2015) also found total pinyon and juniper transpiration was low and 11 percent of annual precipitation over 5 years for a stand with similar basal area of oneseed juniper and twoneedle pinyon and located in the warm Chihuahuan Desert with average precipitation of 14 inches. In wet years or irrigated treatments, trees used more water, but still less than 18 percent of total precipitation (Pangle et al. 2015).

In the studies by West et al. (2008) and Pangle et al. (2015), understory coverage was minimal, indicating much of the annual precipitation is lost through other processes than plant transpiration, such as interception, evaporation, and/or runoff. The third study, Mollnau et al. (2014), was located in Oregon in the cold-dominated Great Basin with mean annual precipitation of 13 inches. This study estimated that transpiration for a stand of western juniper was 0.02 in d^{-1} during the summer months (Mollnau et al. 2014). The stand-level estimates from the studies cited herein are on the low end of the range calculated from a canopy diffusion model, which predicts 15–80 percent transpiration loss from pinyon and juniper woodland (Lane and Barnes 1987). Based on seasonal conductance for a Phase III western juniper stand, a transpiration model estimated transpiration accounted for 44 percent of the total precipitation received in 1 year (12.5 inches) (Angell and Miller 1994). This highlights the complexities of measuring the water budget and scaling up individual measurements to the stand-level (Wilcox et al. 2003a). Sap flow can underestimate transpiration due to limited numbers of probes, variations in actual sapwood area, failure to adequately characterize radial variation in sap flow rates, thermal gradients, and power supply problems (Čermák et al. 2004; Clearwater et al. 1999).

Total Evapotranspiration

Total evapotranspiration can be measured at the ecosystem level by mounting instruments on tall towers above the tree canopy to determine the outgoing flux of water vapor; the current method is referred to as eddy covariance estimates. Eddy covariance data for Utah juniper measured the highest evapotranspiration rates in March and April of 0.06 in d^{-1}; the remainder of the growing season rates were below 0.04 in d^{-1} (Leffler et al. 2002). However, there is a lack of studies on evapotranspiration of pinyon and juniper woodlands at this ecosystem scale.

Effects of Disturbances and Land Management Practices

Numerous empirical assessments and modeling studies have assessed the effects of pinyon and juniper die-off or removal on evaporation, transpiration, interception, snow ablation (the sum of snow evaporation and sublimation), snow accumulation, and streamflow timing and magnitude (see review by Adams et al. 2012). In these dryland regions where precipitation is usually below 20 inches, conflicting results have been reported in the literature. Adams et al. (2012) proposed a conceptual model for assessing potential hydrologic consequences of large landscape-scale tree die-offs. The authors' conceptual framework is also relevant for a variety of tree-removal conditions. Tree removal can alter shading and solar radiation inputs; directly diminish transpiration and interception; reduce surface roughness, and thereby increase wind speeds; and facilitate night-time cooling by elevating outgoing longwave radiation at night through loss of the

warm air trapping effect. The net effect of these opposing processes determines whether more or less water is available, as depicted in the authors' conceptual model. The results of these processes are generally more ambiguous in regions where annual precipitation is less than 20 inches because almost all water is lost to evapotranspiration regardless of vegetation type. The complexities lie in separating these terms into their component parts. In wetter regions, conversion of woody vegetation to shrubs and grasses is known to produce a reduction in evapotranspiration because of the removal of more deeply rooted species (Zhang et al. 2001).

Williams et al. (2014a) suggested that tree removal through fire may serve as an ecohydrologic threshold reversal mechanism over time on juniper-dominated sagebrush rangelands. The authors suggested that, over time, tree removal by fire or cutting potentially increases soil water availability (Bates et al. 2000; Roundy et al. 2014a) and thereby enhances understory vegetation (fig. 4-12; Roundy et al. 2014b) that improves infiltration (Williams et al. 2018a), reduces runoff and erosion (Pierson et al. 2007; Williams et al. 2018a), and promotes persistence of a sagebrush and native herbaceous plant community (Bates et al. 2014; Chambers et al. 2014; Miller et al. 2013, 2014; Roundy et al. 2014b; Williams et al. 2017). Roundy et al. (2017) further suggested tree removal by chaining combined with seeding, served in the same manner, and found that the treatment increased intercanopy vegetation and reduced runoff and erosion from natural rainfall events on a pinyon and juniper woodland in Utah. Williams et al. (2018) suggested that studies of pinyon and juniper woodland ecohydrologic responses to tree removal across the Great Basin and Colorado Plateau depend on effectiveness of treatments to enhance intercanopy vegetation. Overall, the impacts of disturbances and

Figure 4-12—The response of this site to fire was largely due to a good cover of bluebunch wheatgrass prior to the event. Increased herbaceous cover improves infiltration and reduces runoff and erosion. (Photo courtesy of Northwest Watershed Research Center, USDA Agricultural Research Service, Boise, Idaho.)

land management actions on water and erosion in woodlands then depend on the degree to which those perturbations alter the vegetation structure and associated hydrologic processes (Kormos et al. 2017b; Ludwig et al. 2005; Niemeyer et al. 2016; Ochoa et al. 2018; Pierson et al. 2007; Roundy et al. 2017; Wilcox et al. 2003a; Williams et al. 2016a, 2019).

Drought

The literature is particularly limited regarding drought impacts on water availability in pinyon and juniper woodlands. Recent landscape- to regional-scale die-offs of pinyon and juniper in the southwestern United States have been attributed to periods of drought and associated limited soil water availability, plant water stress, bark beetle infestations, and reduced tree regeneration (see Section 2—Climate Controls on Pinyon and juniper Distribution).

There are few studies to indicate how drought and mortality of pinyon and juniper will affect hydrology and erosion. Allen and Breshears (1998) and Wilcox et al. (1996a) chronicle how prolonged drought at a site in the Jemez Mountains of northern New Mexico in the 1950s facilitated landscape-scale plant community transition from ponderosa pine to twoneedle pinyon-oneseed juniper vegetation and thereby altered runoff and erosion processes. The authors indicated that fire suppression in the years prior to the study, and dating back to the 1880s, allowed pinyon and juniper trees to establish beneath and adjacent to ponderosa pines (Allen and Breshears 1998). Drought and subsequent beetle infestations in the 1950s contributed to ponderosa pine mortality and allowed the more drought tolerant pinyon and juniper trees to dominate site resources. Herbaceous cover was not evaluated at the site in the 1950s, but the authors contend that herbaceous cover at the site was likely low then, declined with conversion to a pinyon and juniper woodland, and approached approximately 2 percent at the time of the Allen and Breshears (1998) study. Overgrazing and vegetation competition for limited soil water facilitated increases in bare ground at the site over the mid- to late-1900s, culminating in extensive and well-connected bare intercanopy area and amplified erosion (Wilcox et al. 1996a).

Wilcox et al. (1996a) estimated from a 2-year study that annual runoff at the site accounted for less than 10 percent of the annual water budget, but that there was little storage of runoff across the site at the watershed scale. The studies by Allen and Breshears (1998) and Wilcox et al. (1996a) do not necessarily indicate that runoff increased following the vegetation type conversion from ponderosa pine to pinyon and juniper woodland, but increased erosion at the site as reported by the authors suggests runoff may have been elevated in association with the plant community transition.

In general, increased runoff and erosion are likely during high water input events where cover is decreased by disturbance (Pierson et al. 2011; Williams et al. 2014a), but research regarding increased plot- to hillslope-scale runoff and erosion associated with drought are scant in the literature. Guardiola-Claramonte et al. (2011) evaluated streamflow for eight basins over a four-State regional area in the southwestern United States with recent (2000s) drought-related die-off of pinyon pine. The study found that streamflow for the study basins declined over 3- to 6-year periods after pinyon die-off and that only a small portion of the decline was attributable to climate variability (Guardiola-Claramonte et al. 2011). The snowline elevation in these watersheds was above the pinyon die-off, thus differences in snow processes were not a plausible explanation (Guardiola-Claramonte et al. 2011). Based on literature, the authors imply that the streamflow reductions were most likely due to increased soil water use associated with increases in understory vegetation following tree die-off and perhaps amplified evaporation from surface soils (Guardiola-Claramonte et al. 2011).

A similar study by Biederman et al. (2015) evaluated streamflow for eight catchments of the Colorado River that underwent substantial tree die-off associated with bark beetle infestations. That study found that streamflow, evaluated over nearly a decade after tree die-off, decreased in three study catchments and exhibited no change in the remaining five study catchments. The authors suggested the results reflect increased water use by residual vegetation and possibly increased water losses to snow sublimation and evaporation following die-off (Biederman et al. 2015). To date, there is little evidence that drought-related changes to vegetation in pinyon and juniper woodlands significantly affect water availability at the annual time scale, particularly in climate regimes where evapotranspiration demands commonly exceed precipitation.

Fire

Consumption of canopy and groundcover by fire reduces interception capacity and surface water retention and increases the quantity and intensity of water arrival at the soil surface and the flow volume and velocity across it (fig. 4-13; DeBano et al. 1998; Shakesby and Doerr 2006). The amount of additional water input made available by burning is dependent on the interception and storage capacity of residual cover and how quickly postfire ground cover returns. General estimates suggest that the quantity of interception by unburned rangeland trees, shrubs, and grasses approximates 0.04–0.08 inches (1–2 mm) of rainfall per storm (Bonan 2002), depending on the cover biomass, rainfall intensity and duration, cover moisture content, and the horizontal and vertical arrangements of cover elements. The conversion of interception loss and stemflow to rainfall arrival at the soil surface is nearly 100 percent where severe burning uniformly removes canopy and groundcover.

Figure 4-13—Consumption of canopy and groundcover by fire in the first year reduces interception capacity and water retention at the soil surface. It increases the quantity and intensity of water arrival at the soil surface and the flow volume and velocity across it. Recovery of this site in years 2 and 3 will depend on prefire herbaceous vegetation or seeding, postfire precipitation, and fire severity. (Photo courtesy of Northwest Watershed Research Center, USDA Agricultural Research Service, Boise, Idaho.)

Estimates are limited regarding fire-induced increases in soil water availability for woodlands. Roundy et al. (2014a) found that prescribed fire and mechanical tree-removal treatments in late succession woodlands of the Great Basin increased available water in the resource growth pool in the growing seasons by 26, 20, 15, and 19 days in the first through fourth year after burning, respectively. The overall additional time that water was available each year posttreatment decreased as plant cover increased.

Seyfried and Wilcox (2006) suggested that woody plant removal by burning can increase deep soil water, but only where soils are deep enough to store excess water below the rooting zone. Postfire reductions in raindrop intensity are as important as changes in the quantity of water (Shakesby and Doerr 2006). Greater raindrop impact after canopy and groundcover removal results in increased soil detachment from rainsplash processes (Pierson et al. 2008b, 2009, 2013, 2014; Williams et al. 2014a,b, 2016a). Reductions in groundcover abate surface retention of overland flow, allowing flow to concentrate and move downslope with greater velocity, erosive energy, and transport capacity (Al-Hamdan et al. 2012a, 2012b, 2013; Pierson et al. 2009, 2011; Williams et al. 2014a,b, 2016a). The potential overall effect is a decrease in the time to runoff generation and an increase in cumulative runoff and sediment yield over the duration of a storm event.

Overall, the degree to which fire affects infiltration and runoff and erosion processes depends on the magnitude of alterations to soil properties, amount, and recovery time of vegetation and litter cover as well as inherent site attributes such as soil type, slope angle, and topography (Pierson et al. 2011; Shakesby and Doerr 2006; Williams et al. 2014b). For snow-dominated environments, burning of vegetation may alter snow accumulation, timing of runoff initiation, cessation, peak flow within the year, and amount of snowmelt runoff. Burning may also result in increased surface temperatures and snowmelt rates due to greater incoming solar radiation postburn. Any reduction in vegetation, therefore, reduces snow accumulation and water availability for biological processes and streamflow generation. Reduced snow retention also potentially alters runoff characteristics from summer thunderstorms on water-limited sites by inhibiting vegetation production and groundcover recruitment. Where snow does accumulate, runoff responses to mid-winter rain-on-snow events may be substantial after burning (see Marks et al. 2001 and Pierson et al. 2001).

A number of rainfall simulation experiments have been conducted in burned and unburned areas of pinyon and juniper woodlands and document fire effects on plot-scale infiltration, runoff, and erosion for these communities (table 4-2; Pierson et al. 2013, 2014, 2015; Roundy et al. 1978; Williams et al. 2014a, 2018). Roundy et al. (1978; table 4-2) measured infiltration and erosion immediately after and 1 year after burning on a singleleaf pinyon-Utah juniper site. Rainfall was applied at 3.31 in h^{-1} for 1 hour across dry and wet antecedent moisture conditions. Infiltration was generally similar across burned (2.85–3.23 in h^{-1}) and unburned (3.08–3.28 in h^{-1}) shrub and tree canopy areas for the dry soil conditions, and was lower in burned shrub plots (2.25–2.68 in h^{-1}) than burned tree plots (2.58–3.07 in h^{-1}) for wet soil conditions. Interspaces generally exhibited the lowest infiltration rates and burned interspaces (0.89–1.52 in h^{-1}) had substantially lower infiltration relative to burned tree and shrub plots (2.63–2.66 in h^{-1}) for wet soil conditions.

In a multi-site study of burned pinyon and juniper woodlands in the Great Basin, Pierson et al. (2013, 2014) and Williams et al. (2014a) applied rainfall at 2.52 in h^{-1} for 45 minutes for the dry soil conditions and 4.02 in h^{-1} for 45 minutes for the wet soil conditions, 1 and 2 years after fire. In those studies (table 4-2), fire had varying impacts on infiltration and runoff generation, with the main impact being reduced infiltration and increased runoff from burned relative to unburned tree plots at two of three sites. Soils were water repellent on burned and unburned tree plots. Litter on unburned plots buffered

repellency effects on runoff generation. Burning had no significant impact on sediment yield from the singleleaf pinyon-Utah juniper site, but increased sediment yield by three- to sevenfold for tree and shrub plots at the Utah juniper site (Pierson et al. 2014). For the western juniper woodland, burning increased sediment yield for wet soil conditions in the first year following fire by 34-fold for tree plots, 24-fold for shrub plots, and 4-fold for interspace plots (Pierson et al. 2013; Williams et al. 2014a).

Overall, burning created more uniform conditions at the fine spatial scale, resulting in greater amounts of runoff and/or sediment for transport to coarser scales in the first year postfire (Pierson et at. 2013, 2014; Williams et al. 2014a). Pierson et al. (2015, table 4-2) applied the same rainfall rates to 140 ft^2 plots on the same sites as in the Pierson et al. (2014) study 1 year postfire. High runoff and sediment yield at the coarser scale persisted in intercanopy areas after burning at the singleleaf pinyon–Utah juniper site, but runoff and sediment yield were largely unaffected by burning in tree canopy areas at that site. In contrast, runoff and sediment yield increased dramatically (approximately 8-fold and approximately 30-fold, respectively) after burning tree plots and remained high in intercanopy areas at the Utah juniper site.

In the Pierson et al. (2013) and Williams et al. (2014a) studies, high levels of runoff and sediment yield persisted one year after burning in the intercanopy and burning increased runoff and sediment yield by approximately 6-fold and more than 20-fold, respectively. Rainfall simulation methodologies and plot size in that study were consistent with those in the Pierson et al. (2015) study. The studies by Pierson et al. (2013, 2015) and Williams et al. (2014a) all attribute increases in postfire runoff and erosion following burning to accumulation of runoff and sediment sources from fine scales into high velocity concentrated overland flow over coarser scales. Burning in the studies created more homogeneous bare ground conditions at all three sites, and the variation in hydrologic and erosion responses across sites postfire reflects differences in initial vegetation and surface conditions and soil type across the three sites.

Studies by Williams et al. (2018a,b) and Nouwakpo et al. (in review) repeated the experiments of Pierson et al. (2015) in the summer of 2015, 9 years after burning. Williams et al. (2018a,b; fig. 4-6) measured increases in herbaceous cover within the intercanopy 9 years postfire, resulting in improved infiltration and reduced runoff and sediment yield from interspaces by more than twofold. On larger scale plots, reductions were 3- to 7-fold for intercanopy runoff and 3– to more than 75–fold for intercanopy sediment yield for the highest intensity storm at both sites (Nouwakpo et al. in review). Those studies support the importance of postfire herbaceous groundcover recovery to enhance infiltration and limit runoff and sediment transport to the hillslope scale. Collectively, the rainfall simulations discussed here demonstrate that fire can impart an initial increase in runoff and sediment yield on woodlands sites depending on initial vegetation and soil attributes, and that, where burning enhances herbaceous cover, improved infiltration and reduced runoff and erosion at the plot to hillslope scales are likely over time (Nouwakpo et al. in review; Williams et al. 2018a). At the watershed scale, peak discharge rather than cumulative runoff tends to be greater after burning, and is most pronounced after short-duration, high intensity, convective thunderstorms over large expanses of severely burned landscapes (Shakesby and Doerr 2006). Estimates are limited regarding fire impacts on watershed scale runoff and sediment yield from woodlands. Studies from mountainous forested settings indicate hillslope erosion can approach 24–40 t ac^{-1} yr^{-1} the first few years following burning, and recovery to prefire erosion rates may take 4 to 7 years (Robichaud 2009; Robichaud et al. 2008). Debris flows are uncommon for woodlands following burning, but have been documented in the literature (Cannon et al. 1998, 2001).

Mechanical Tree Removal

In contrast to fire, mechanical treatments can retain much of the existing understory vegetation and therefore typically pose few negative impacts on hydrology and erosion (Miller et al. 2013, 2014; Roundy et al. 2014a, 2014b; Williams et al. 2019). Bates et al. (2000) found that tree cutting at a western juniper woodland increased soil water availability at 0–8 inch and 8–16-inch soil depths in each year of a 2-year study, and that the greater soil water availability in the cut versus an uncut areas resulted in greater total understory plant biomass. As noted above for fire, Roundy et al. (2014a) found tree removal increased the number of wet days up to 26 days when applied to sites with high tree cover and that soil water was available 8.6 days and 18 days longer in treated versus untreated areas the fourth year posttreatment where tree removal was applied at moderate to high tree cover. Also, the authors noted that the additional time that water was available each year posttreatment decreased as plant cover increased.

Increases in the number of wet days were similar for mechanical and prescribed fire treatments in that study of 13 woodland-encroached sagebrush rangelands in the Great Basin (Roundy et al. 2014a). Mollnau et al. (2014) assessed soil water depletion over a 2-year period for a western juniper site on plots approximately 65 x 65 feet and spanning a variety of cover conditions resulting from vegetation manipulations including juniper removal. The authors found that spring season soil water content in the top 24 inches of soil was 4.2 inches on juniper-dominated plots with a shrub and herbaceous understory as compared to 5.3 inches on shrub- and herbaceous-dominated plots where trees had been removed and 6.1 inches on plots primarily with bare ground. Spring season soil water content over the same depths was 4.5 inches for both juniper-dominated plots without a shrub and herbaceous understory in comparison with the shrub and herbaceous-dominated plots in which trees were removed. Over depths of 24 inches to 35 inches, spring season soil water content was lower for plots with juniper cover (2.6 inches) relative to plots without juniper cover (3.5 inches). Soil water content over 0–24 inches depth by the fall season was similar across juniper plots (2.6 inches) and shrub and herbaceous covered plots (3.2 inches) and was highest for the primarily bare plots (5.4 inches).

Mollnau et al. (2014) attributed the seasonal differences in soil water contents across cover types to differential use of soil water to meet plant needs on vegetated plots, potentially greater interception loss on juniper plots, and minor evaporative losses from bare plots. The authors further suggested evaporation accounted for soil water depletion only to about 6-inch soil depth. Based on regression analysis of seasonal soil water content at different depths, Mollnau et al. (2014) concluded that juniper, shrubs, and herbaceous plants all shared soil water resources in the upper 24 inches of the soil profile, that juniper was the primary user of soil water below this depth, and that juniper water use limited deep soil recharge and seasonal soil water carryover. However, lack of differences in fall season soil water across the juniper-dominated versus shrub and herbaceous-dominated plots suggests that available soil water is readily used by whatever vegetation occupies a respective site. This is similar to the Roundy et al. (2014a) study in which increases in the number of wet days declined with time after tree removal as the understory responded to available soil water. In the winter months in central Oregon western juniper depleted winter soil moisture at 20 inches, if subsoil temperatures were above freezing (Jeppesen 1978). Where soils remained frozen or woodlands had been thinned, soil moisture was significantly higher.

A substantial number of studies have evaluated the effects of mechanical treatments on hillslope runoff and erosion processes (table 4-2; Cline et al. 2010; Hastings et al. 2003; Jacobs 2015; Pierson et al. 2007, 2013, 2015; Roundy et al. 2017; Williams et al. 2019). At the fine spatial scale, Cline et al. (2010) and Pierson et al. (2014) found that

placing shredded tree mulch and debris on 5.4 ft^2 interspace plots enhanced infiltration and reduced runoff and erosion from high intensity rainfall (2.52 in h^{-1} and 102 in h^{-1}, 45-minute durations) in a Utah juniper woodland. Sediment yield during application of the highest intensity on mulch-covered interspace plots was more than fivefold less than from mulch-free interspaces (Pierson et al. 2014). Cline et al. (2010) reported that mulch residue reduced sediment yield from the same simulated storm by nearly twofold for grass interspaces and by eightfold for bare interspaces. The study further found that bare interspaces with tire tracks from the shredding equipment generated the highest amount of sediment during rainfall simulations, but these areas were reasonably surrounded by areas with masticated debris (Cline et al. 2010).

Pierson et al. (2013, 2015) found that cutting and placing downed pinyon and juniper trees in the intercanopy had no immediate beneficial impact on runoff and erosion rates at multiple woodland sites in the Great Basin. In those studies, runoff tended to route through downed trees where there were voids in contact of the tree debris with the ground surface (fig. 4-14). In a followup study of the sites, Williams et al. (2019) found that runoff and erosion from overland flow were greatly reduced by downed trees 9 years after cutting. The downed trees 9 years after cutting had settled into place and were in good contact with the soil surface. Downed trees and debris detained concentrated flow releases during overland flow experiments and allowed more time for water to infiltrate and for sediment deposition (Williams et al. 2019). This supports the common postfire rehab practice of placing downed logs (usually trees felled as part of suppression/mop-up and hazard tree-removal operations) across the slope—sometimes staking them in place to prevent rolling downhill—to decrease erosion. Pierson et al. (2007) found that

Figure 4-14—Placing downed pinyon and juniper trees on the intercanopy had no immediate beneficial impact on runoff and erosion rates at multiple woodland sites in the Great Basin. In those studies, runoff tended to route through downed trees. However, 9 years following treatment, runoff and erosion from overland flow were greatly reduced. (Photo courtesy of Northwest Watershed Research Center, USDA Agricultural Research Service, Boise, Idaho.)

intercanopy runoff and erosion from rainfall simulations (2.17 in h^{-1} intensity, 60-minute duration,) in a cut western juniper woodland were substantially less than in an adjacent uncut control woodland 10 years after cutting. The authors concluded that increased herbaceous cover 10 years following cutting improved infiltration and limited formation of concentrated overland flow within the intercanopy.

Roundy et al. (2017) compared runoff and sediment from natural rainfall events on intercanopy plots (approximately 110 ft^2) in chained-and-seeded and untreated areas of a pinyon and juniper woodland in Utah over a 5-year period. The site frequently received rainfall from high intensity summer monsoonal thunderstorms. Chaining and seeding increased vegetation and reduced bare ground by threefold relative to the untreated area. The authors estimated that chaining and seeding reduced runoff and sediment by 5– to 10–fold as averaged over the 5-year study.

Hastings et al. (2003) found that cutting pinyon and juniper and evenly distributing tree debris (lop-and-scatter) within the intercanopy reduced erosion from high intensity rain events on a degraded and rapidly eroding twoneedle pinyon-oneseed juniper woodland in New Mexico. Erosion from natural rainfall events over two rainy seasons was one to three orders of magnitude more for untreated than treated micro-watersheds (3,230–11,840 ft^2 area). Hastings et al. (2003) attributed the reduced erosion following tree cutting to enhanced infiltration and soil water retention afforded by slash, herbaceous cover recruitment, and reduced interconnectivity of runoff and sediment source areas. Jacobs (2015) assessed cover, runoff, and erosion responses to the treatments at the Hastings et al. (2003) study sites over a 16-year period posttreatment. During that time, the sites underwent a multi-year drought, wildfire, and beetle outbreak (Jacobs 2015). Treated areas more rapidly revegetated and improved in hydrologic function relative to untreated areas following the disturbances, and therefore the authors concluded that the treated areas exhibited greater resilience to perturbations than the untreated areas.

Collectively, these field studies demonstrate that mechanical tree-removal treatments can effectively improve infiltration and reduce hillslope runoff and sediment yield where the treatments enhance vegetation and groundcover and reduce bare ground.

Studies of the effectiveness of mechanical tree-removal treatments to increase watershed streamflow have produced mixed results. In a paired watershed study, Deboodt (2008) determined that tree cutting in a snow-dominated western juniper woodland reduced overall water use for transpiration during the cool season, and thereby allowed soil water to increase over the year, yielding higher end-of-year deep soil water content in cut versus uncut juniper woodlands. He also found that tree cutting had a favorable effect on groundwater levels and springflow, but treatment effects on streamflow were difficult to discern from variability in precipitation input. Ochoa et al. (2018) studied the cut and uncut watersheds from the Deboodt (2008) study 13-years postcutting. The authors found that the timing and amount of precipitation strongly influenced soil water recharge and that increased soil water recharge during snowmelt led to a rapid water table rise and streamflow. That study detected 1.5- and 1.7-fold greater peak streamflow and springflow rates in the cut versus uncut watershed and annual streamflow was 3.6 times greater for the cut watershed over the 4-year study period.

However, Ochoa et al. (2018) noted that annual streamflow and spring flow prior to the treatments were on average 1.8 and 3 times greater for the watershed subsequently cut in comparison with the control watershed. The authors did not explicitly state that interception loss affected soil water recharge but reported that up to 46 percent of annual precipitation was intercepted. Niemeyer et al. (2016) and Kormos et al. (2017a) suggested through modeling that juniper dominance on mid elevation snow-dominated sagebrush rangelands can alter the distribution and amount of snow accumulation across a watershed, and thereby affect the spatial distribution of and the timing and delivery of water availability for soil

water recharge and streamflow (e.g. Flerchinger and Cooley 2000; Seyfried et al. 2009; Williams et al. 2009). The Kormos et al. (2017a) study applied 6 years of measured and modeled data to determine that woodland-dominance of 4 small sagebrush watersheds in southwest Idaho limited accumulation of snow in deep drifts (fig. 4-15). The authors found that the more evenly distributed snow cover under the juniper-dominated condition resulted in earlier spring snowmelt and summer streamflow cessation relative to conditions dominated by sagebrush cover. The Deboodt (2008), Ochoa et al. (2018), and Kormos et al. (2017a) studies were on sites in which precipitation occurs primarily as snow and streamflow occurs mostly as cool season runoff.

Wilcox (1994) summarized results from a number of mechanical tree-removal studies aimed at increasing streamflow from southwestern U.S. woodlands and found that results varied substantially with runoff regime, summer thunderstorm driven versus dominated by cool season frontal rains, snowmelt, or rain-on-snow water input. The Cibeque Ridge paired watershed study (table 4-1) in Arizona found that chaining pinyon and juniper combined with slash burning and seeding increased streamflow the first 2 years posttreatment on a 100-acre watershed relative to an adjacent control watershed of the same size, but streamflow in the subsequent year declined to that below the untreated watershed, presumably due to increased transpiration losses associated with seeded grasses (see Ffolliott and Gottfried 2012). At two watersheds in the Beaver Creek Experimental watershed in Arizona (table 4-1), 100 percent removal of pinyon and juniper trees had no effect on water yield. However, a third watershed targeted only 83 percent of juniper with herbicide—and this increased annual streamflow 65 percent for the first 4 years and 157 percent after 8 years (Clary et al. 1974). The increase in streamflow translated on area basis to 0.49 inches y^{-1}. However, after 8 years, dead trees were removed and post treatment streamflow returned to pretreatment levels (Zou et al. 2010). This suggests that the actual disturbance from the tree-removal treatments reduced infiltration in the other two watersheds and/or removal of canopy cover increased evaporation. And, it seems plausible that the remaining pinyon trees and dead standing juniper trees continued to modify the near-surface energy balance and reduce evaporation in the third watershed. Results from the study are also consistent with the idea that juniper extracts deeper sources of water that recharge streamflow (Deboodt 2008; Mollnau et al. 2014).

As indicated above in the discussion of drought, the limited research on streamflow patterns following large-scale tree die-off on woodlands and pine forests in the

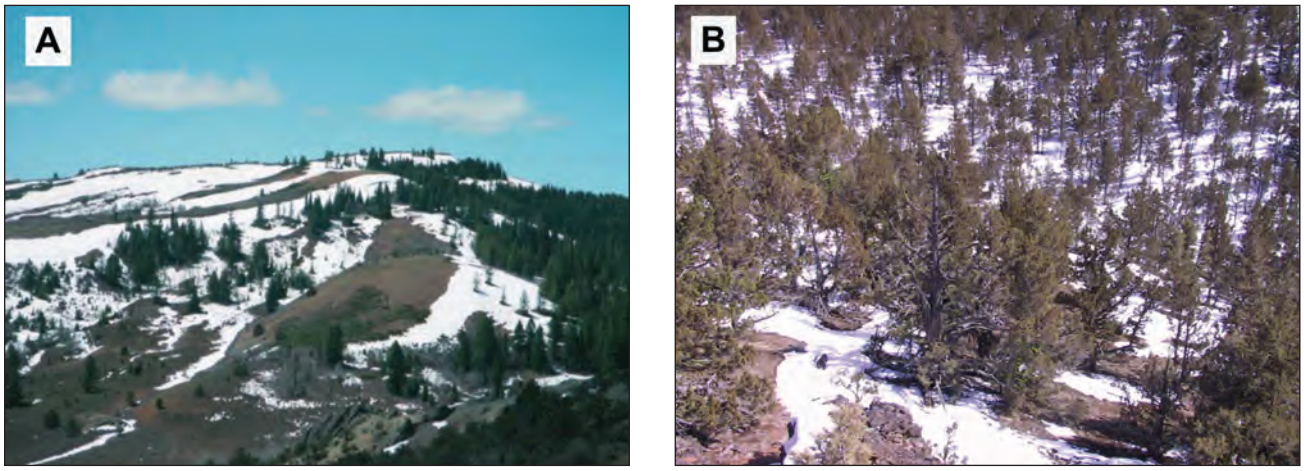

Figure 4-15—Photographs showing snow accumulation in (A) drifts in sagebrush dominated areas of the USDA Agricultural Research Service, Reynolds Creek Experimental Watershed, Idaho and (B) more uniform snow distribution at a western juniper dominated sagebrush site in the South Mountain study area (Kormos et al. 2017; photographs provided by the USDA Agricultural Research Service, Northwest Watershed Research Center, Boise, Idaho).

southwestern United States indicate that runoff is unchanged by tree reductions in mixed-phase precipitation climates (Biederman et al. 2015; Guardiola-Claramonte et al. 2011). Overall, the literature suggests increases in soil water and streamflow associated with mechanical tree removal vary with climate regime in addition to site-specific attributes of the area treated. More long-term studies are needed to definitively state whether mechanical tree removal, as well as tree removal in general, is effective at increasing streamflow across various ecoregions containing pinyon and juniper woodlands. For more detailed discussion on tree-reduction practices on vegetation and water, see Section 5, Restoration and Management.

SECTION 5: RESTORATION AND MANAGEMENT

Some assume that managing rangelands for presettlement conditions can successfully maintain sustainability and biodiversity into the future. But this paradigm is challenged by several factors—a continually changing climate, new species introductions, and changing disturbance regimes.

Summary

Vegetation management of pinyon and juniper woodlands began primarily after World War II, when fuel costs were low, and a large surplus of heavy mechanical equipment became available. The primary goals were to increase livestock forage production, improve watersheds to prevent downstream flooding of towns (which occurred along the Wasatch Range in Utah), and improve declining big-game winter habitat (Aro 1975; Dwyer 1975; Terrel and Spillett 1975). In the 1950s and 1960s, the primary method for tree removal was chaining, which often included broadcast seeding between chainings to introduce perennial grass species (Aro 1975). At the time there was little distinction made between pre- and postsettlement woodlands or the resilience and resistance to invasive species of the areas to be treated, which led to mixed results.

Two-way chaining with broadcasting seeding between chainings provided the best results for increasing perennial grass cover. By the 1970s, the acres of rangelands chained annually declined significantly, but chaining is still being used at smaller scales. When applied properly, chaining and other treatments can provide good results. Since 2000, shredding (mastication) and cutting have become the most common mechanical methods of tree removal. Both treatments often ultimately result in increases in available soil water, length of growing season, and shrub, perennial grass, and forb cover (Bates et al. 2000; 2017b; Miller et al. 2014b; Roundy et al. 2014a; Young et al. 2013a). Variation in cutting treatments include cut-and-leave; cut-limb-and-scatter; cut-and-broadcast burn; and cut-pile-and-burn—all with advantages and disadvantages. Tree removal in Phase III woodlands by mastication or cutting can increase the growing season by 2 or more weeks. Response of invasive annual grasses is always a concern and is closely linked to pretreatment tree and perennial herbaceous cover, and soil moisture and temperature regimes. Locations with warmer fall temperatures are especially susceptible to cheatgrass dominance, while those with cooler fall seasons and relatively wet winters and springs are more resistant.

Seeding is an important consideration where native perennials are depleted and soil moisture temperature regimes are favorable for invasive annuals (Bybee et al. 2016). Successful seeding can significantly reduce the abundance of annual grasses following mechanical treatment. A major disadvantage of mechanical treatments compared to

prescribed fire is the survival of small trees (less than 6 feet tall) and resprouting from remaining basal limbs, which can significantly reduce the longevity of the treatment, often requiring followup treatments. Abundance of slash must also be dealt with in late succession phases.

The broad-scale application of herbicides to mature woodlands has been limited due to mixed results and concerns related to impacts on native perennials and water. But the use of Picloram ™ has proven to be an effective tool following mechanical treatment when applied selectively on small trees or resprouts at the base of the trees. It has also been used to treat invasive annuals following tree removal, a consideration on sites with low resistance to invasive plants.

Although early studies evaluating the effects of prescribed fire were conducted in the early 1950s, the use of prescribed fire was very limited until the 1970s (Blackburn and Bruner 1975). Federal and State agencies were hesitant to use prescribed fire for fear of escaped fires, and limited surface fuels in many pinyon and juniper woodlands required extreme weather conditions to carry fire. In the early 1970s, a survey of burned woodlands reported increases in postfire perennial grasses. Between 2002 and 2016, 5.5 million acres were prescribed burned in the West. Prescribed fire has proven to be a useful tool under the right conditions. However, under the wrong conditions (closely linked to characteristics of the site), it can significantly increase invasive annuals.

When treating woodlands, the key components to success are an adequate level of residual perennial herbs present on the site and ecological site characteristics including soil texture, depth, and moisture and temperature regimes (Miller et al. 2013). The relative dominance of trees to perennial understory vegetation at the time of treatment is closely linked to plant succession following treatment. The vast majority of studies comparing mechanical versus prescribed burning reported larger increases (at least in the first few years following treatment) of invasive annuals in the burn treatments, especially on warm and dry compared to cool and moist sites. The advantages of fire are the removal of small trees, little to no resprouting, and costs that are typically less than most mechanical treatments. However, disadvantages are the removal of important nonsprouting shrub species (although these are often lacking in Phase III) and a greater threat of invasive species.

The lack of surface fuels in late Phase II and III areas also usually requires a pretreatment such as cutting a portion of the trees to conduct a prescribed burn under moderate weather conditions. Recovery of the perennial herb layer to preburn or greater levels typically takes 2–3 years versus in mechanical treatments—for which increases can occur in the first posttreatment year. However, burning Phase III woodlands under more severe conditions will significantly increase perennial grass mortality (more than 80 percent). Prescribed fire also greatly reduces residual cover of sagebrush and bitterbrush if they are still present in the understory. Recovery of sagebrush canopies to 20–30 percent cover on cool and moist sites usually takes 20–35 years. On warm and dry sites, sagebrush recovery takes considerably longer. Over the past 70 years our goals for restoration have broadened to maintaining or restoring ecosystem function. We have also learned that short- and long-term vegetation responses following treatment are closely related to the woodland successional phase, residual understory vegetation at the time of treatment, and soil moisture and temperature regimes in addition to management. However, invasive plants have proven to be an ever-increasing challenge, especially on warmer and drier sites with warm springs and falls. Sites with drier or cooler falls, and wet winters and springs favor perennial herb cover.

Introduction

Evolution of Rangeland Management

Initial observations and concerns about woodland expansion were noted in the early and mid 1900s (Cottam 1929; Cottam and Stewart 1940; Leopold 1924; Nicol 1937; Woodbury 1947). Until World War II, tree removal was done with handsaws and axes—primarily to obtain material for fenceposts, for fuel, and (in Nevada, Utah, and eastern California) for conversion of pinyon to charcoal for mining during the Comstock period. The use of heavy machinery, power saws, prescribed fire, and chemicals for tree removal did not begin in the West until after World War II (fig. 5-1). A surplus of heavy equipment and low fuel costs following the war led to the mechanization of management for semiarid landscapes. Aircraft were used for fire suppression and to spray herbicides across large swaths of land. Crawler tractors were used to plow roots, push trees over, and to pull plows, pipe harrows, anchor chains, roller cutters, and seed drills. Between the late 1940s and the 1970s the most common tree-removal methods on BLM lands in Utah, Colorado, Arizona, and Nevada were chaining, bulldozing, and cabling (Aro 1975; Redmond et al. 2014). Beginning in the 1970s, hand-cutting with chainsaws became the primary method used in central Oregon (Winegar and Elmore 1978) and later in southern Idaho and eastern California. Shredding became the mechanical method of choice in Utah starting around 2003. Beginning in the late 1970s and 1980s, prescribed burning became more common for treating rangelands, alongside mechanical treatment.

The primary goals of tree removal in the ’50s, ’60s, and early ’70s were to increase forage production, improve watershed conditions, and enhance deer winter range (Johnson 1967; Terrel and Spillet 1975). During this period, treatment rarely distinguished between persistent versus newly expanded woodlands. By the early 1970s, concern about possible woodland mismanagement (Dwyer 1975) increased when observations of understory responses to tree removal were not always positive (Arnold et al. 1964; Blackburn and

Figure 5-1—Mechanical treatments including shredding (2006, foreground), thinning, and chaining have created a more diverse landscape mosaic, increasing both herbaceous vegetation and shrubs in 2018. We have learned much from our past successes and failures. Eastern Nevada. (Photo by Rick Miller, Oregon State University.)

Bruner 1975; Clary 1971, 1974; O'Rourke and Ogden 1969). Since then, objectives for tree removal on public lands have increasingly focused on watershed improvement, fuel reduction, wildlife habitat, and restoration of sagebrush ecosystem function. Funding for tree removal since 2000 has come largely from fuel reduction and sage-grouse habitat restoration budgets. The threat of sage grouse listing as a threatened or endangered species in 2002 resulted in an influx of financial resources directed toward improving and protecting sage grouse habitat (Miller et al. 2017). But it is increasingly recognized that in order for management actions to have long-term benefits in these semiarid ecosystems, goals and objectives need to focus on long-term maintenance and restoration of ecosystem structure and function, rather than on one particular factor in that system (Benson 2012; Boyd et al. 2014; Miller et al. 2017).

Management Today

One of the most frequent questions that managers grapple with is how resistant a particular site is to invasive annual plants—and how various treatment methods might influence the magnitude of their increase or eventual decline. The complex answer is—it depends. Long-term effectiveness of vegetation management on ecosystem function depends on a complex set of interacting factors that drive plant succession across spatially and temporarily dynamic Great Basin and Colorado Plateau ecosystems. The benefits and drawbacks of vegetation management on ecosystem function are closely linked to the type and severity of treatment as well as ecological site characteristics, pretreatment vegetation composition, and posttreatment management. Vegetation management to limit conifer expansion into shrub-steppe and shrubland communities must be developed with clearly defined objectives and all of the above factors in mind.

The ability to predict plant succession following various vegetation treatments is one of the most important skills a land manager can employ. Several key questions help to identify the best treatment strategy for a given ecological site and to predict potential outcomes (fig. 5-2; Miller et al. 2014a, 2015). These questions address the potential for resilience and resistance to invasive plants for the area to be treated. They include:

1) What are the ecological site characteristics of the area to be treated that will influence resistance to invasive annuals?
2) What is the current vegetation on the site?
3) How will different treatment methods influence posttreatment succession and invasive annuals?
4) What are the nonsprouting shrubs on the site?
5) What is the erosion potential if plant cover is temporarily reduced?
6) Will the density of small trees (less than 4 feet tall) require followup treatments?
7) Are surface fuels (less than 3.3 feet tall) adequate to carry fire under moderate weather conditions? Or is pretreatment required?
8) Will posttreatment fuel loads be acceptable?

From chaining to prescribed fire, managers over the years have adopted various methods to manage pinyon/juniper landscapes in attempt to reach specific ecological goals. The discussion below addresses the history, strengths, and drawbacks of various treatments and what we know about how these complex semiarid ecological systems respond to the impacts of treatment.

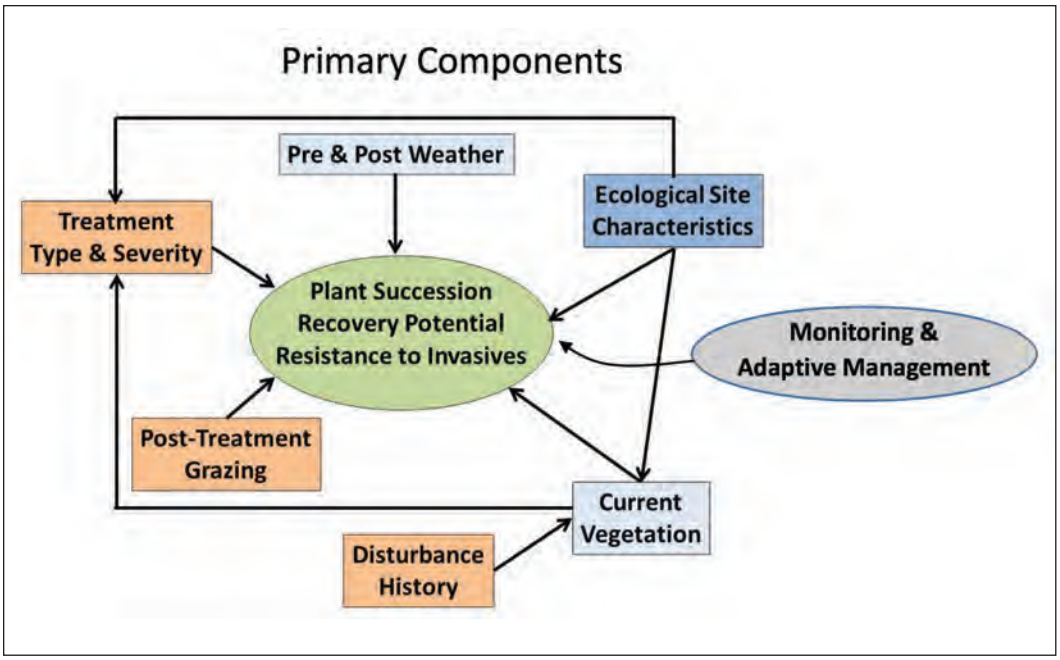

Figure 5-2—A conceptual model of the primary components that drive successional trajectories following vegetation management treatment. Consideration of key characteristics of these primary components substantially increases the ability to predict outcomes following disturbance and vegetation management (Miller et al. 2013, 2014a).

Chaining

In the Intermountain West, pulling anchor chains across the landscape was the most widespread method for pinyon and juniper removal from the late 1940s through the 1960s (fig. 5-3; Arnold et al. 1964; Aro 1975; Cotner 1963). Use of the method peaked in 1967, when a total of 80,000 acres were chained, and then declined to less than 5,000 acres in 1972. By the early 1970s, an estimated 514,000 acres of BLM land had been chained, with the largest proportion occurring in Utah (table 5-1; Aro 1975). Chaining fell out of favor in the 1970s as a result of high fuel prices, the indiscriminate selection of sites treated, high levels of soil disturbance, and the rise of the environmental movement—resulting in the increase of public concern. However, with the proper application of modern methods and careful site selection, chaining can be a useful tool for rehabilitation (fig. 5-4).

Chaining involves dragging a ship anchor chain, 200–500 feet long, between two bulldozers, pulling out large woody plants. Early work in Utah found 60– to 90–pound links were most effective, and that the addition of several swivels in the chain decreased the accumulation of debris caught up in the chain, reducing surface disturbance (Vallentine 1971; Steve Monsen, Retired Revegetation Specialist, USDA Forest Service, Rocky Mountain Research Station, Provo, Utah; and Richard Stevens, Biologist, Utah Division of Wildlife Resources, Provo, Utah, personal communications, 2017). Various modifications could also be made to the chain including welding 18-inch pieces of railroad rails or bars to the individual links. Bars were welded perpendicular to the chain links on the Ely Chain and parallel to the links on the Sagar Chain. Chaining was done (frequently, but not always) parallel to the slope contour, which reduced power requirements and diminished potential erosion by leaving both soil furrows and brush windrows parallel to the contour. A length-to-swath ratio for the chain of 2:1 to 3:1 was recommended. It was pulled in a J-shape for increased effectiveness of uprooting trees.

Figure 5-3—In the Intermountain West, pulling anchor chains across the landscape was the most widespread method for pinyon and juniper removal from the late 1940s through the 1960s. Under the right conditions it can be a useful tool to retain a portion of the shrubs and increase seed establishment by seeding between chainings. This image shows the first growing season after chaining. Schell Creek Range, eastern Nevada. (Photo by Rick Miller, Oregon State University.)

Table 5-1—Acres of pinyon and juniper woodlands chained by the BLM between 1960 and 1972 (Aro 1975).

State	Acres (x 1,000)	Percent
Utah	257	50
Colorado	93	18
Arizona	61	12
New Mexico	46	9
Nevada	43	8
Oregon, Idaho, and California	14	3
Total	**514**	

Increasing the distance between dozers in the second pass (resulting in a gentler curve in the chain) could increase the survival of sagebrush in the understory (Cody Coombs, Hazardous Fuels Program Manager, BLM, Ely, Nevada, personal communication, 2018).

In the late 1960s and early 1970s, the cost of chaining ranged from $15–$18 per acre (without posttreatment seeding) and jumped to as much as $33 per acre with followup hand-cutting of small trees (Winegar and Elmore 1978). In 2016, chaining cost estimates were around $90 to $150 per acre (Brad Washa, State Fuels Specialist, BLM, Utah; and Cody Coombs Hazardous Fuels Program Manager, BLM, Ely, Nevada, personal communications, 2017, 2018). Chaining is generally less expensive than cutting or shredding, and is still used in vegetation management.

Approximately 11,000 acres were chained between 2013 and 2017 in eastern Nevada. Two tractors, 100–150 feet apart, pulling a 200-foot chain, could treat 5–15 acres per

Figure 5-4—Broadcasting seed between chainings in 2013 resulted in more than 30 percent cover of perennial grasses and increasing sagebrush cover on this productive mountain big sagebrush-bluebunch wheatgrass site on moderately deep Mollisol soils. Photo taken in 2018. Schell Creek Range, eastern Nevada. (Photo by Rick Miller, Oregon State University.)

hour and cause 28–95 percent tree mortality—depending on tree size and density as well as terrain (Arnold et al. 1964; Aro 1975; Plummer et al. 1968; Vallentine 1971). Tree reductions in both cover and density were usually greater for pinyon than juniper (Tausch and Tueller 1977). Chaining resulted in greater tree mortality in even-aged stands where trees were 15–25 feet tall (Cotner 1963) than when trees were less than 6 feet tall. Across Nevada, chained sites where tree cover was reduced by 84 percent (Tausch and Tueller 1977) were again dominated by trees within 40 years of chaining (Bristow et al. 2014). In some cases, tree densities increased following chaining, resulting from the release of small trees (Aro 1975) and establishment of new trees (Winegar and Elmore 1978). In Utah, 75 percent of the trees present 25 years after chaining had established prior to treatment (Van Pelt et al. 1990). In central Nevada 40–50 years after chaining, tree cover was 23.5 percent—compared to 0.3 percent in an adjacent burned area (Bristow et al. 2014).

Two-way chaining (repeating the treatment in the opposite direction from the first chaining) significantly increases tree mortality compared to single chaining, but costs more. Two-way chaining doubled the cost but reduced Utah juniper cover from 35.5 percent to 4.1 percent (Skousen et al. 1986). This method is desirable when seeding is necessary because it allows seeds to be broadcast between chainings, which covers a portion of the seed and improves seedling establishment compared to just broadcast seeding (Aro 1971, 1975; Ott et al. 2003). Near Ely, Nevada, broadcasting a seed mix of natives and introduced species between chainings resulted in successful establishment (fig. 5-4; Cody Coombs, Hazardous Fuels Program Manager, BLM, Ely, Nevada, personal communication, 2018). Chaining burned woodlands may also help bury seed for more successful revegetation by breaking up soil water repellent layers (Madsen et al. 2012a). To increase the longevity of chaining treatments, followup vegetation management of small trees and basal sprouting is typically required.

Vegetation Response

In northern Arizona, chaining increased herbaceous vegetation production from 200 to 700 pounds per acre and increased the abundance of winterfat, cliffrose, and bitterbrush (Aro 1971), which suggests that in this case, native vegetation dominated the understory prior to treatment. Native shrubs also increased across five sites in Utah following chaining (Skousen et al. 1986, 1989). Chaining can result in a high percentage of old shrubs being killed, but most young shrubs survive (Skousen et al. 1986, 1989; Tausch and Tueller 1977). In Utah, however, on sites where shrubs and native perennial grasses were severely depleted, chaining plus seeding in the 1950s and 1960s often resulted in a conifer dominated overstory with an understory of introduced perennial grasses (fig. 5-5a,b; Steve Monsen, Retired Revegetation Specialist, USDA Forest Service, Rocky Mountain Research Station, Provo, Utah, personal communication, 2018). Shrubs did not recover 50–60 years following treatment. When native perennial grass cover is severely depleted (less than or equal to 5 percent cover), cheatgrass will often dominate following chaining in the absence of seeding (Davis and Harper 1990; Tausch and Tueller 1977; Ott et al. 2003). In central Nevada, where perennial grass cover was low prior to treatment, cover remained low 50 years following chaining (Bristow et al. 2014).

Chaining and Seeding

The vast majority of studies show significant increases in perennial grasses following chaining of depleted understories that were seeded to introduced perennial grasses. Seed was typically broadcast before or between chainings (Juran et al. 2008; MacDonald 1999; Ott et al. 2003). Establishment of seedling plants following a broadcast seeding (without covering the seeds) frequently resulted in limited or no success on warm and dry (mesic/aridic) ecological sites. Increased success of greater perennial grass cover (largely crested wheatgrass and intermediate wheatgrass) on the chained areas resulted in lower cheatgrass cover (Ott et al. 2003). But there are limitations to this approach—introduced species can decrease establishment of desirable native perennial species resulting in an alternative seeded state (Davies et al. 2013; Knutson et al. 2014; Lesica and Deluca 1996). To maintain biodiversity and a predominance of native plants, several things are needed—increased development of native plant materials (Ott et al. 2003), improved methods of planting natives, and increased availability of local native seed for planting (Plant Conservation Alliance 2015; Steve Monsen, Retired Revegetation Specialist, USDA Forest Service, Rocky Mountain Research Station, Provo, Utah, personal communication, 2017).

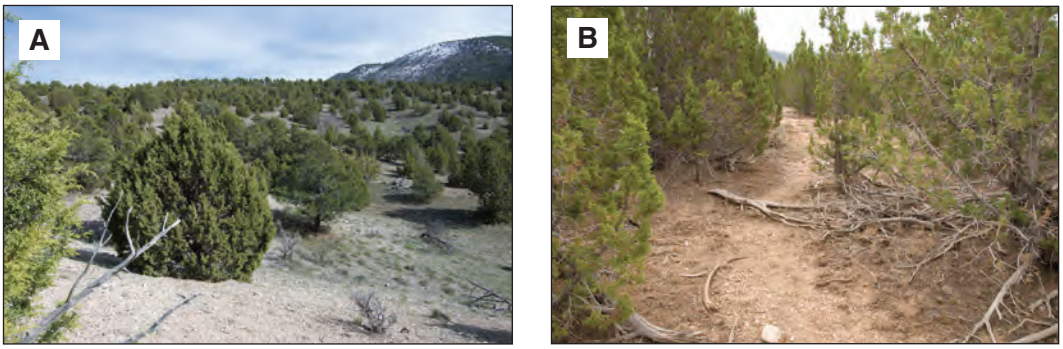

Figure 5-5—(A) This late Phase II woodland was chained and seeded with introduced grasses in the early 1960s. Few shrubs, native grasses, or forbs are present. A thinning stand of introduced grasses still persists as the tree canopy continues to increase. Many of these trees were likely small saplings at the time of the chaining. Understory was also likely severely depleted. (B) Early 1960s chaining with no seeding. Currently a closed Phase III woodland with Sandberg bluegrass in the understory and no shrubs or deep-rooted perennial grasses. West slope of the Wasatch Range near Ephraim, Utah. (Photos by Rick Miller, Oregon State University.)

Soil Disturbances Related to Shredding

The impact of chaining on water runoff and sediment yields depends largely on the slope angle and changes in the abundance and density of ground surface cover, surface roughness, compaction, soil characteristics, and soil disturbance (Gifford 1973a, 1973b, 1975; Gifford and Tew 1969; Gifford et al. 1970; Myrick 1971). Maintaining the rotation of the chain to limit the accumulation of debris greatly minimizes soil surface disturbance (fig. 5-6). Herbaceous vegetation cover on a site with high erosion potential following chaining and seeding in Utah was 23.5 percent on treated and 4.5 percent on untreated plots (Roundy et al. 2017). Runoff and sediment yields were 4.5 and 10 times lower, respectively, on treated than untreated sites.

Windrowing

Windrowing was a method used in the ’60s and ’70s that involved chaining followed by dozers piling or “windrowing” downed trees (Aro 1975). The method has proven to be highly successful, especially where seeds were drilled following windrowing. It is, however, expensive, as it requires one to two passes with the chain, followed by a third pass with heavy equipment to pile the debris (in addition to seeding), and it can potentially result in considerable soil disturbance. Thus, its use has been limited (Steve Monsen, Retired Revegetation Specialist, USDA Forest Service, Rocky Mountain Research Station, Provo, Utah, personal communication, 2016).

Dozing

In the past, bulldozing was used to reduce tree densities and open woodland canopies by pushing over and uprooting trees (Vallentine 1971). The method was best adapted for

Figure 5-6—First growing season following a two-way chaining and seeding with a mix of native species. Maintaining the rotation of the chain to limit the accumulation of debris greatly minimizes soil surface disturbance and retains a higher percentage of shrubs. Center of the photo shows an area heavily disturbed by debris accumulation on the chain. Chaining typically requires close supervision by the land manager in charge. Schell Creek Range, eastern Nevada. (Photo by Rick Miller, Oregon State University.)

removing scattered stands of low-density trees. It had less impact on shrubs than chaining (Skousen et al. 1989). But dozing was ineffective for removing small trees and left large pits and upturned soil. During the 1940s, Hula dozing was one of the most widespread methods for tree removal in the Southwest (Steve Monsen, Retired Revegetation Specialist, USDA Forest Service, Rocky Mountain Research Station, Provo, Utah, personal communication, 2016). The Hula dozer is a power-controlled tilt dozer blade with four teeth, which allowed operators to control blade angle and tilt (Vallentine 1971).

Shredding

Since 2003, shredding—also referred to as mastication, chipping, or mulching—has become a common method for tree removal in Utah (fig. 5-7). It is a process in which trees are shredded into small pieces using machinery carrying a rotating cylinder of cutting teeth (e.g., Bull Hog). The amount of mulch deposited from the treatment depends on the size and density of trees under treatment, but typically ranges from 0.4–7.9 inches (10–200 mm) deep on the ground, distributed within a few feet of the masticated tree. Mulch induces the increase in nitrogen mineralization at 5.9–6.7 inches (150–170 mm), which can result in increases in both cheatgrass and bluebunch wheatgrass (Aanderud et al. 2017). Over time, the positive effects increased for bluebunch wheatgrass and declined for cheatgrass.

Between 2012 and 2015 in Utah, over 61,569 acres of pinyon and juniper woodland were shredded, at an approximate cost of $280–$300 per acre (Brad Jessop, Natural Resource Specialist, BLM, Salt Lake City, Utah; and Brad Washa, State Fuels Specialist, BLM, Salt Lake City, Utah, personal communication, 2017).

Figure 5-7—First growing season following shredding of a Phase II woodland, with an understory of native grasses and shrubs. The resilience and resistance to invasives of this site is high. (Photo courtesy of Northwest Watershed Research Center, USDA Agricultural Research Service, Boise, Idaho.)

Response to Shredding

Reducing tree competition by shredding results in significant increases in soil water availability and surface litter biomass. Masticated surface litter can affect vegetation recovery, surface fuel loads, and soil moisture and temperature. Thick debris from shredding can suppress plant establishment (fig. 5-8; Kane et al. 2010; Young et al. 2013a). Masticated debris layers concentrated around the tree and existing tree litter limit seed-soil contact and seedling access to light, reducing germination and establishment. However, debris from shredding can enhance seedling establishment by lengthening the period of soil water availability, which can increase the growth and biomass of both invasive plants and perennial grass seedlings (Young et al. 2013a,b). Little work has been done to evaluate the life or rate of tree recruitment following shredding treatments. However, longevity of the treatment relates directly to the density of small trees remaining on the site, potential seed sources, and resprouting from basal limbs remaining after shredding (fig. 5-9).

Response to Shredding: Perennial Grasses and Forbs

Across multiple sites in Utah with a range of pretreatment tree cover, shredding that reduced tree cover by at least 20 percent resulted in a twofold to threefold increase in tall perennial grass cover (fig. 5-10; Bybee et al. 2016). On Shay Mesa in southeastern Utah, masticated sites had 24 percent perennial grass and 17 percent forb cover while perennial grass and forb cover were less than 1 percent on untreated sites (Ross et al. 2012). In several studies, perennial grass cover on masticated plots was also greater compared to sites treated with lop-and-scatter and cut-pile-and-burn (Bybee et al. 2016; Ross et al. 2012; Shakespear 2014;). In these studies, shrub cover was relatively unchanged by shredding in the first few posttreatment years.

Figure 5-8—Thick mulch layer following a recent shredding of a late Phase II woodland. Schell Creek Range, eastern Nevada. (Photo by Rick Miller, Oregon State University.)

Figure 5-9—Shredding and cutting can result in resprouting at the base of both Utah and western junipers, usually in the axis of the branch and trunk. A followup treatment is often required to increase the life of the treatment. (Photo by Rick Miller, Oregon State University.)

Figure 5-10—Nine years following a shredding and no seeding of a late Phase II and III woodland. The treatment resulted in a significant increase in native deep-rooted perennial grasses, primarily bluebunch wheatgrass, along the east slopes of the Egan Range in eastern Nevada. Note the limited amount of mulch remaining on the site. High elevation, cold winters, and precipitation of more than 12 inches make this black sagebrush and mountain big sagebrush bluebunch wheatgrass site resilient and resistant to invasive grasses. Egan Range, Nevada. (Photo by Rick Miller, Oregon State University.)

Shredding and Invasive Annuals

The way invasive annual plants respond following shredding is closely linked to pretreatment tree and perennial herbaceous cover. On tree-dominated, masticated sites (Phase III), where few pretreatment shrubs and perennial grasses remain, resistance to invasive weeds was very low (Bybee et al. 2016). In southeastern Utah, increases in invasive annual cover were greater on masticated plots compared to untreated plots but less than on plots that were cut, piled, and burned (Ross et al. 2012) or broadcast burned (Redmond et al. 2014). However, Redmond et al. (2014) reported the increase in invasive plants was greater on masticated plots than on plots that were cut, piled, and burned regardless if they were seeded or not seeded following treatment. The mixed response of invasive plants among studies is likely related to differences in the pretreatment vegetation composition, posttreatment disturbances (e.g. seeding), and ecological site characteristics (fig. 5-2; Bybee et al. 2016; Ross et al. 2012; Young et al. 2013a).

Shredding and Seeding

Seeding is an important consideration where native perennials are depleted, and invasive annual grasses pose a threat (Bybee et al. 2016). Cheatgrass cover increased after shredding—or seeding and then shredding—but was considerably less (less than 10 percent cover) where perennial herbaceous cover was 43 percent (fig. 5-11). In northwestern Colorado, Stephens et al. (2016) compared no seeding and seeding a native mix of grasses, forbs, and shrubs on untreated and masticated plots in western Colorado. Biomass of perennial grasses was 160 kg/ha in masticated-and-seeded and masticated-and-unseeded treatments compared to 10 kg/ha in untreated plots. There was no difference between seeded and unseeded masticated treatments. The lack of difference between seeding and no seeding may have resulted from the presence of an adequate understory prior to treatment or poor reseeding success.

Figure 5-11—Twelve years following shredding and seeding on a site with a residual cover of sagebrush—resulting in a strong response of shrubs and grasses. Limited mulch remains. Eastern Nevada. (Photo by Rick Miller, Oregon State University.)

But in another study, the perennial herbaceous cover on seeded plots increased 234 percent and 160 percent in masticated and broadcast burn treatments, respectively—compared to only 32 percent on masticated unseeded plots (Redmond et al. 2014). When 22 shredded sites across Utah were compared to adjacent untreated sites, those seeded before shredding (largely to introduced species) had greater cover and density of perennial forbs, tall grasses, and sagebrush than untreated sites (Bybee et al. 2016). Cover and density trended higher on seeded than nonseeded shredded plots, but differences were not statistically significant. Seeding did suppress increases in cheatgrass. For cheatgrass, cover remained around 5 percent when shredding was followed by seeding on plots where pretreatment tree cover was more than or equal to 35 percent. In contrast, cheatgrass cover was more than 16 percent on masticated plots with no seeding when pretreatment tree cover was more than or equal to 25 percent (Bybee et al. 2016). Many of the seeds broadcasted before shredding end up covered or buried by tractors during the shredding process. Proper seed burial can greatly increase revegetation success in semiarid environments (Ott et al. 2003; 2016; Roundy and Call 1988; Stevens et al. 2004). Managers often prescribe seeding in conjunction with shredding if either cheatgrass cover or lack of perennial plant cover is a concern.

Soil Disturbances Related to Shredding

Soil compaction from the tires of shredding equipment impacted 15 percent of a treatment area in Utah, but compaction effects can be reduced if shredding operations are conducted when soils are dry. Dodson et al. (2006) found soil compaction significantly increased in the upper 4 inches of soil where rubber-tired skidders were used to remove cut western juniper in central Oregon. Compaction of soil decreased infiltration rates, increased runoff and sediment yield, and reportedly increased penetration resistance threefold. However, effects of compaction may be offset by the reduction in bare ground from shredded debris. On masticated plots, infiltration rates were reduced in the tire tracks of the grass interspace (Cline et al. 2010). However, nontire impacted interspace and tree mounds were unaffected, and infiltration rates higher and cumulative runoff and sediment yields lower on interspace plots with shredded residue. Ross et al. (2010) reported that soil aggregate stability was higher on masticated than untreated plots on Shay Mesa, Utah, where bare ground was 26 percent on treated and 54 percent on untreated plots. Shredding also increased percent total nitrogen and soil organic carbon in the top inch of the soil by the second year following treatment (Aanderud et al. 2017; Young et al. 2014).

Fuel Loads and Shredding

Shredding significantly increases surface fuel loads, and the increases in surface fuel biomass are closely related to pretreatment tree cover (figs. 5-7, 5-8, 5-12, 5-13; Young et al. 2015). Changes in surface fuel abundance, structure, and compaction in masticated plots may result in lower fire intensities (Shakespear 2014), but the potential for longer soil heating may result in higher fire severities (see Glossary for definition). Shredding transforms trees into surface fuels of compact 1- and 10-hour size classes, reducing fire intensity and rate of spread (Young et al. 2015). Winter burning on frozen soils has been found to reduce fire effects on woodlands that have been cut (Bates et al. 2006; Bates and Svejcar 2009), but this has not been tested on masticated woodlands.

Cutting

Historically, cutting pinyon and juniper trees for firewood, fenceposts, and conversion to charcoal for silver mines was common in the late 1800s and early 1900s. With the closure of mines and conversion to the use of chemicals for mineral extraction (rather than wood heat), woodcutting for mining significantly declined. Just before World War

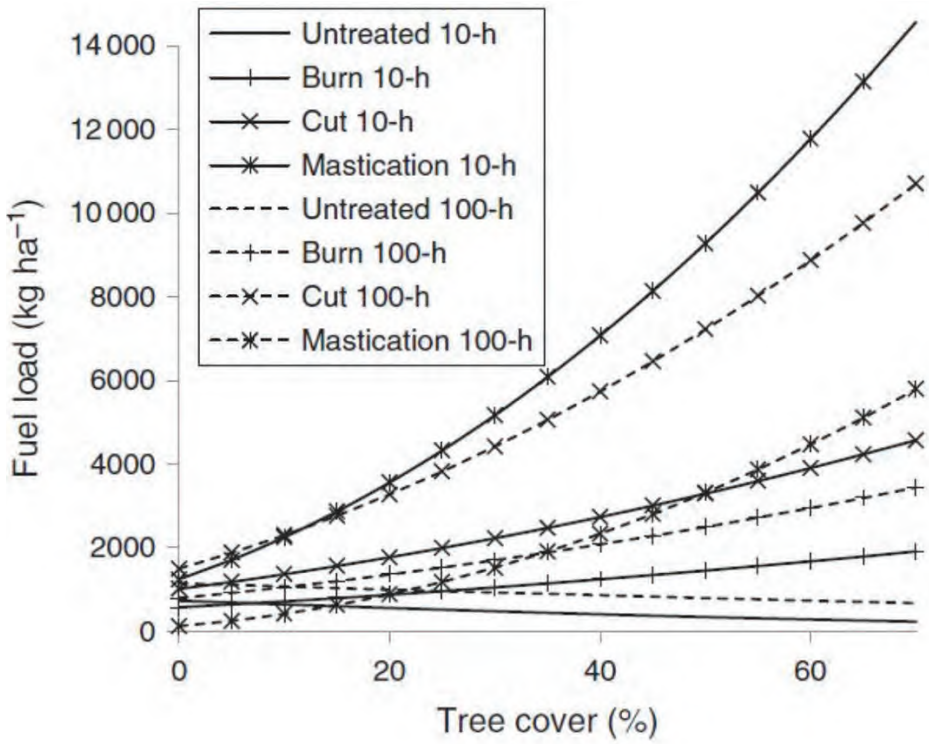

Figure 5-12—Comparison of biomass of surface fuel loads for untreated and three different tree reduction treatments 1-year posttreatment separated by time-lag fuel moisture (TLFM) class (from Young et al. 2015).

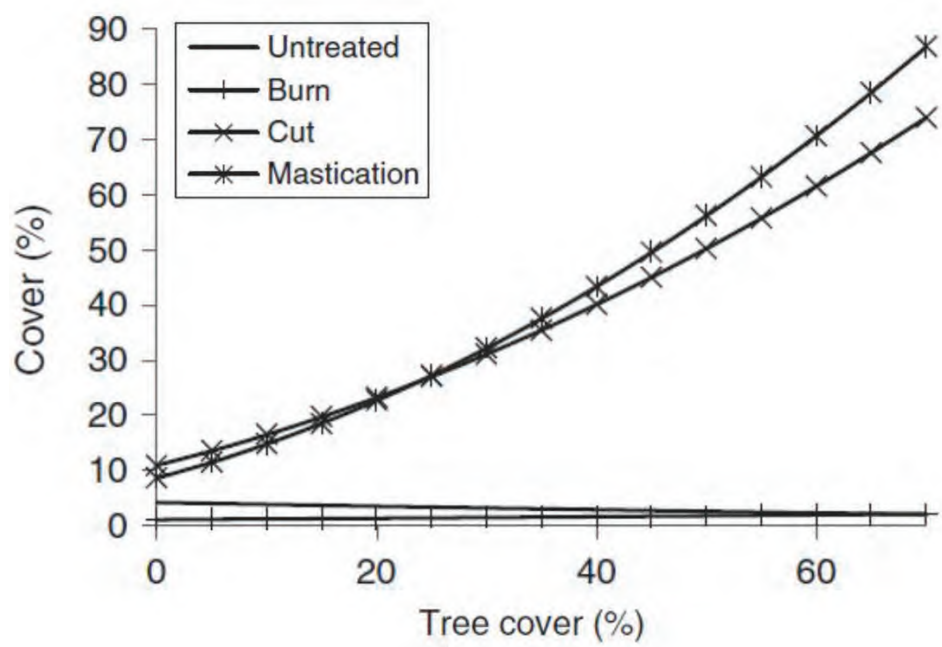

Figure 5-13—Percent cover of surface fuels (dead organic material) 1-year posttreatment in relation to pretreatment tree canopy cover among untreated and three different tree reduction treatments (from Young et al. 2015).

II, woodcutting occurred primarily for firewood and fenceposts. Following the war, pinyon and juniper woodlands cut with chainsaws in the name of restoration and/or forage production between the 1940s through the early 1970s was limited. In Vallentine's (1971) *Range Improvements* textbook, cutting was described as highly selective but expensive because of labor costs. In central Oregon, beginning in the early 1970s, hand-cutting with chainsaws became the primary tool for juniper removal in open stands where understory vegetation was present and could respond to competitive release (Winegar and Elmore 1978). In the late 1970s and early 1980s, cutting expanded into eastern Oregon, northeastern California, and southwest Idaho. By 1976, 12,500 acres of western juniper were thinned or cleared using chainsaws in Oregon at a cost of $5–$28 per acre (Winegar and Elmore 1977). Cutting significantly increased in the mid-'90s especially in the Columbia Basin in central Oregon, in an attempt to increase ground cover for watershed restoration and streamflow to address concerns over the listing of salmon as an endangered species (Tim Deboodt, Retired County Extension Specialist, Oregon State University, Crook County, Oregon, personal communication, 2017). Cutting remains a primary method for conifer removal today, especially for sage-grouse habitat restoration in Phase I and early Phase II woodlands (Miller et al. 2017).

Cutting is a highly selective management method of tree removal. Like shredding, it becomes especially useful when retention of shrubs—especially sagebrush—is a primary management goal. There is also a broad seasonal window for cutting, which is limited primarily by access (e.g. winter snows), fire danger, and species of concern (e.g., sensitive nesting periods). Cutting generally results in minimal soil disturbance and a more gradual release of soil nutrients (e.g., nitrogen) compared to fire. There are many variations of cutting and followup treatments, including cut-and-leave; cut-limb-and-scatter (also called lop-and-scatter); cut-and-broadcast burn; and cut-pile-and-burn—all with advantages and disadvantages (table 5-2).

Table 5-2—Advantages and disadvantages of different variations of hand cutting (Miller et al. 2005, 2013)

Method	Advantages	Disadvantages
Cut-and-leave	Decreases bare ground. Least expensive cutting method. Highly selective.	Leaves too much material on the ground in mid-phase II and III. Can have smothering effect causing mortality of perennial herbs. Misses small trees requiring follow-up treatment.
Cut-lop-and-scatter	Increases cover of slash. Highly selective. Minimal smothering effect.	Leaves too much material on the ground in mid-phase II and III. Increases cost. Misses small trees requiring follow-up treatment.
Cut-and-broadcast burn	Removes high amounts of slash in Phase II and III. Increases treatment longevity by killing small trees.	Not selective resulting in loss of nonsprouting shrubs. Increases cost. Increases availability of soil nutrients (e.g., N) which can reduce resistance to invasive species
Cut-pile-burn	Removes high amounts of slash in Phase II and III. Selective, minimizes area burned. Broad seasonal window of when piles can be burned. Minimal burn impact on frozen soils.	Increases cost. Some impact to soils. Misses small trees requiring follow-up treatment. Increases availably of soil nutrients but on a smaller proportion of the treated area as compared to broadcast burning

Vegetation Responses to Cutting

Vegetation response following cutting is influenced by ecological site characteristics and pretreatment tree dominance (TDI or Phase I, II, or III; see Glossary for definitions) and understory plant composition at the time of cutting (figs. 5-2 and 5-14; Bates et al. 2000; Everett and Sharrow 1986b; Miller et al. 2014a,b; Roundy et al. 2014a; Williams et al. 2017). The above components are closely linked to the site's resilience and resistance to invasive annuals (Bybee et al. 2016; Miller et al. 2000; Roundy et al. 2014a; Williams et al. 2017). The majority of studies evaluating cut-and-leave treatments reported increases in perennial understory vegetation (Bates et al. 2000, 2007a, 2017b; Everett and Sharrow 1985a,b; Miller et al. 2014b; O'Connor et al. 2013; Rose and Eddleman 1994; Ross et al. 2012; Roundy et al. 2014a; Vaitkus and Eddleman 1987; Williams et al. 2017). Cutting increases the availability of soil nutrients and water and lengthens the growing season by increasing soil water availability by 2 or more weeks (Bates et al. 2000; Roundy et al. 2014b). Current work following 12–13 years of posttreatment by both fire and mechanical tree reduction shows additional wet days in spring more closely related to October-June precipitation than number of years since treatment (Roundy et al. in review).

One disadvantage of cutting (similar to shredding) is that small trees are easily missed during treatment, and sprouting can occur from branch buds that exist below the cut line. With an adequate seed source and/or density of small trees, woodlands can approach Phase II within 25 to 40 years after treatment, depending on soil water and temperature regime (fig. 5-15; Johnson and Miller 2006; Miller et al. 2000; Tausch and Tueller 1977). In central and southeast Oregon, 300 to 500 small trees per acre were present 3 years after cutting, due to posttreatment seedling establishment and because many small trees were left uncut (Bates et al. 2017b; Winegar and Elmore 1978). On 10 sites across the Great Basin, tree saplings were

Figure 5-14—Ten years following cutting of a Phase II woodland with an intact understory. The treatment resulted in a significant increase in shrubs and perennial grasses and forbs. This mountain big sagebrush/Idaho fescue site has high resilience and resistance to invasive annual grasses resulting from relatively cool falls and wet winters and springs. In comparison, locations with warmer fall temperatures are especially susceptible to cheatgrass dominance (Cline et al. 2018b). Modoc Plateau, northeastern California. (Photo by Rick Miller, Oregon State University.)

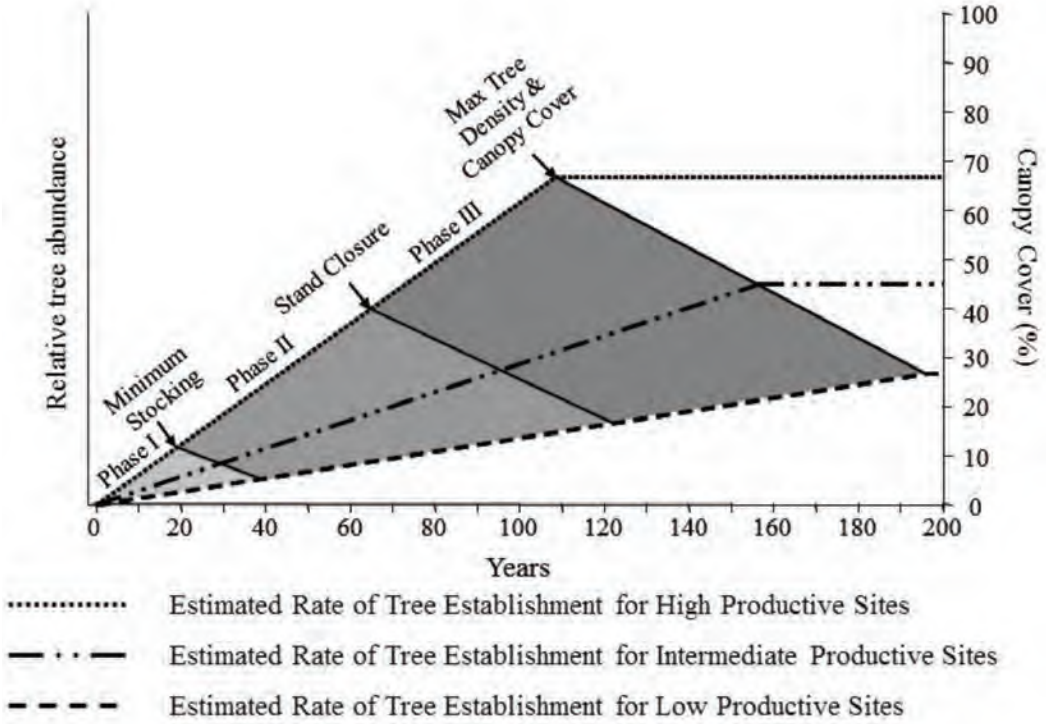

Figure 5-15—The hypothesized time periods from initial tree establishment (early Phase I) to minimum stocking adequate for Phase III, and estimated maximum potential for tree density and cover for stands developing on sites with varying productivity due to differences in elevation and/or exposure (Johnson and Miller 2006).

recorded on 80 percent of cut plots, 53 percent of burned plots, and 32 percent of untreated plots 6 years following treatments (Williams et al. 2017). In southeast Oregon, posttreatment tree cover and density 1 and 25 years following treatment increased from less than 1 percent and 32 trees per acre (all less than 12.6 inches tall) to 4 percent and 132 trees per acre respectively, a level sufficient to fully occupy the site (Bates et al. 2017b).

Shrub Response to Cutting

Shrub retention, especially on warm and dry ecological sites where reestablishment of nonsprouting shrubs can be very limited, is one of the primary advantages of using cutting or cut-pile-burn treatments (fig. 5-16). Cut-pile-burn is a viable option for reducing large amounts of tree slash in Phase II and III woodlands. In Phase I or early Phase II, cut-and-leave is a viable option for maintaining and/or restoring the shrub layer. However, tree removal in Phase III woodlands may not result in quick shrub restoration (Bates et al. 2017b; Roundy et al. 2014a; Williams et al. 2017). Posttreatment increases in total shrub and big sagebrush cover were 25 percent less when the tree dominance index (TDI) exceeded 0.5 (Williams et al. 2017), which is approaching late Phase II. Twenty-five years after cutting in a Phase III woodland, total shrub cover had only increased from 0 to 5.5 percent and sagebrush cover from 0 to 2.8 percent (Bates et al. 2017b).

However, sagebrush density increased from just a trace to 1,700 plants per acre. Sagebrush establishment can also be suppressed by the release of tall grasses when cutting in high tree dominance stands (Phase III) (Roundy et al. 2014a). Across 10 study sites in the Great Basin ranging from cool and moist mountain big sagebrush to Wyoming big sagebrush and mountain big sagebrush communities on cool and moist bordering on warm and dry, sagebrush density 3 years after cutting was 0.41/10 ft^2 on cut and 0.09/10 ft^2 on uncut sites (Miller et al. 2014b). On a cool and moist mountain big sagebrush-mountain

Figure 5-16—Two primary advantages of cutting over burning are retention of sagebrush cover if present, and a smaller response of invasive annuals compared to burning. Disadvantages are the large amount of slash left in late Phase II and III woodlands; followup is usually necessary to remove the small trees and resprouting around lower limbs. East-central Nevada. (Photo by Rick Miller, Oregon State University.)

mahogany community in eastern Oregon, mountain mahogany cover was 12.5 percent greater and density twofold greater 4 years after cutting (O'Connor et al. 2013).

Cutting and Perennial Grasses

Cutting often increases perennial grasses within the first year of treatment, whereas prescribed fire often results in a short-term reduction in perennial grasses followed by an increase (Miller et al. 2013, 2014b). The initial increase in perennial grasses is usually attributed to increased plant size rather than density, emphasizing the importance of pretreatment vegetation composition (Bates et al. 2000; Everett and Sharrow 1986b; Miller et al. 2014b). Increases in perennial grasses following cutting treatment range from 1.4 to 20-fold (Bates et al. 2005; Everett and Sharrow 1985a,b; Miller et al. 2014b; O'Connor et al. 2013; Rose and Eddleman 1994; Ross et al. 2012; Roundy et al. 2014a).

Across a broad range of sites in Oregon, northeastern California, southwestern Idaho, Nevada, and Utah, perennial grass cover was 1.8 times greater than adjacent uncut areas 3 years following treatment (Miller et al. 2014b). In central Nevada, perennial grass cover increased from 5 to 15 percent and 2 to 13 percent following cutting on cool north and west aspects, respectively (Everett and Sharrow 1985b). On warm and dry southern aspects, cover only increased 1 to 3 percent. In eastern Oregon, perennial grass cover was less than 3 percent before cutting but was 10 percent and 13 percent in the 6th and 14th posttreatment years, respectively (Bates et al. 2005). In Phase III woodlands, perennial grass biomass was less than 50 pounds per acre on uncut and 660–1,000 pounds per acre on adjacent cut in the 6th and 14th posttreatment years, respectively. However, 25 years after treatment, perennial grass yields declined from peak posttreatment levels by 30–40 percent (Bates et al. 2017b). The reason for the decline was unknown, but it may be related to an increased presence of woody vegetation or climatic factors. In

western Colorado, where a Phase III tree canopy was 30 percent, perennial grass cover was less than or equal to 1 percent in uncut compared to 11 percent in cut stands 2 years posttreatment (Ross et al. 2012). The majority of studies reported little or no changes in Sandberg bluegrass cover with cutting (Bates et al. 2005, 2017b; Miller et al. 2014b; Vaitkus and Eddleman 1987; Williams et al. 2017), although Bates et al. (2017b) reported a significant increase in Sandberg bluegrass density, which persisted 25 years.

Across multiple sites in the northern and central Great Basin, tall perennial grass cover on plots with high TDI (Phase III) increased 5 percent to nearly 15 percent in the third and over 22 percent in the sixth posttreatment years, resulting in a fourfold increase (fig. 5-17; Roundy et al. 2014a; Williams et al. 2017). In more open conifer stands where TDI was low, perennial grass cover was 17 percent prior to cutting and 22–24 percent following cutting. In comparing cutting and shredding, the response of tall perennial grass cover was similar between the two treatments (Bybee et al. 2016). However, cutting in high TDI or Phase III, can result in greater increases in invasive annual grasses (Roundy et al. 2014a), especially where perennial grass cover is less than 5 percent.

Cutting and Perennial Forbs

Perennial forb cover is typically a relatively small portion of total perennial herbaceous cover and biomass in sagebrush communities and conifer expansion woodlands. In sagebrush communities dominated by Wyoming big sagebrush, basin big sagebrush, and black sagebrush, perennial forb cover is often less than 6 percent (Bates et al. 2017a; Davies et al. 2006; Miller et al. 2014b; Ross et al. 2012; Roundy et al. 2014b; Stringham 2017). In late Phase II and III woodlands, forb cover is usually less than 2 percent (fig. 5-17; Ross et al. 2012; Roundy et al. 2014a; Williams et al. 2017). In several studies, perennial forb cover nearly doubled in cut plots but still remained less than 8.5 percent (Bates et al. 2017a; Miller et al. 2014b; Ross et al. 2012). Increases in perennial forbs following cutting is highly variable. Within the first 3 years of cutting, studies reported increases ranging from 1.5–10 times that of uncut controls (Bates et al. 2017a,b; Miller et al. 2014b; Ross et al. 2012; Roundy et al. 2014a). The wide variation in perennial forb response can be attributed to one or more of the primary components in figure 5-2. The greatest potential increase in perennial forbs following disturbance is on cool and moist compared to warm and dry soils (Miller et al. 2013). In addition, the amount of increase following cutting closely correlated to TDI (Roundy et al. 2014a), but a dry year can modify this response (Williams et al. 2017).

The longevity of increased perennial forb abundance following cutting is considerably shorter than increased levels of perennial grasses (Bates et al. 2017a,b). While undoubtedly the longevity of the perennial forb response is linked to ecological site conditions, posttreatment weather, and foraging pressure, the persistence of increased perennial forb abundance is typically shorter than increased levels of perennial grass abundance (Bates et al. 2017a,b; Williams et al. 2017). In eastern Oregon, perennial forb biomass remained higher than that of adjacent uncut Phase III woodlands for 16 years following cutting. At posttreatment year 24, perennial forb biomass was similar to uncut plots, whereas abundance of perennial tall grasses was still threefold greater in cut plots 24 years postcut (Bates et al. 2017a,b). In Utah, perennial forb cover was initially greater in cut plots but declined to similar levels in untreated plots by 6 years following treatment, possibly a result of increased tall grass cover or below average precipitation (Williams et al. 2017). Type of treatment can also influence the magnitude of increases in perennial forbs. Although cutting can result in increased perennial forb abundance, increases are usually greater in prescribed burn treatments (Miller et al. 2013; 2014b). On 11 study sites across the Great Basin, perennial forb cover was 1.8-fold greater on cut treatments and 2.6-fold greater on prescribed burned compared to adjacent untreated plots (Miller et al. 2014b).

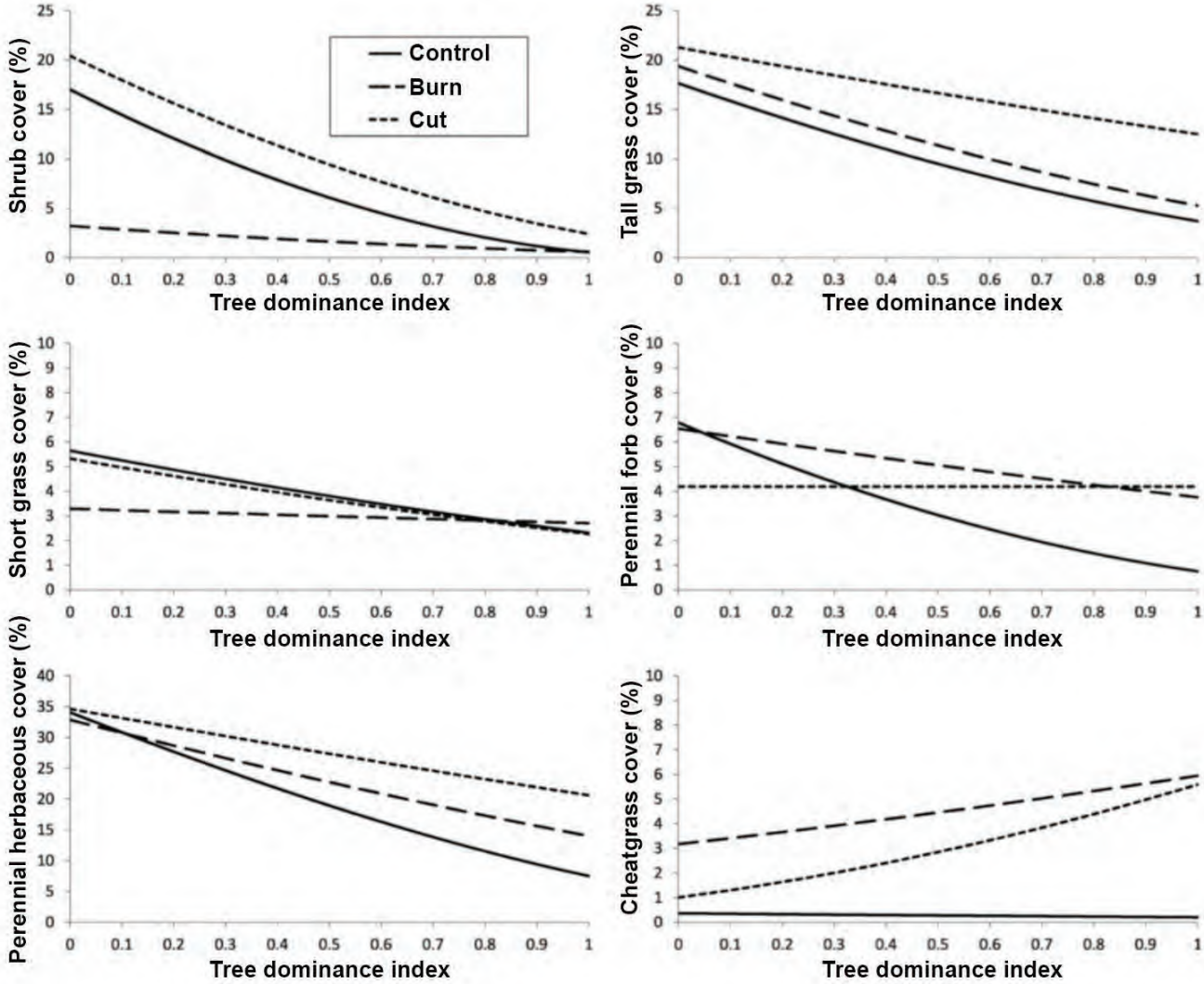

Figure 5-17—Vegetation cover 3 years after treatment in relation to pretreatment tree dominance index (TDI) for multiple sites across the Great Basin (from Roundy et al. 2014a).

Invasive Annual Plant Response to Cutting

The presence of cheatgrass and other nonnative annuals often increases following cutting (Bates et al. 2000, 2005, 2017b; Miller et al. 2014b; Roundy et al. 2014a). However, the magnitude and timing of these increases depends on pretreatment plant composition, soil moisture and temperature regimes, and how the severity of the treatment influences the seed pool, disturbance of the soil surface, and mortality of understory perennial vegetation (Miller et al. 2013). In western Colorado, invasive annual grasses increased just slightly and accounted for less than 2 percent of the total understory cover in an area where annual grass cover was only a trace in control plots (Ross et al. 2012). Across 24 sites in the Great Basin, cheatgrass cover generally decreased with increasing perennial cover, but the ratio of cheatgrass to perennial grass cover increased exponentially with pretreatment tree dominance (TDI values above 0.7, see Glossary) (fig. 5-18; Roundy et al. 2014a). Baughman et al. (2010) reported a similar relationship was reported in east-central Nevada following thinning trees to 25 per acre in Phase II and III sites. Increasing levels of invasive annuals were significantly greater on treated Phase III sites where perennial understory vegetation was less abundant.

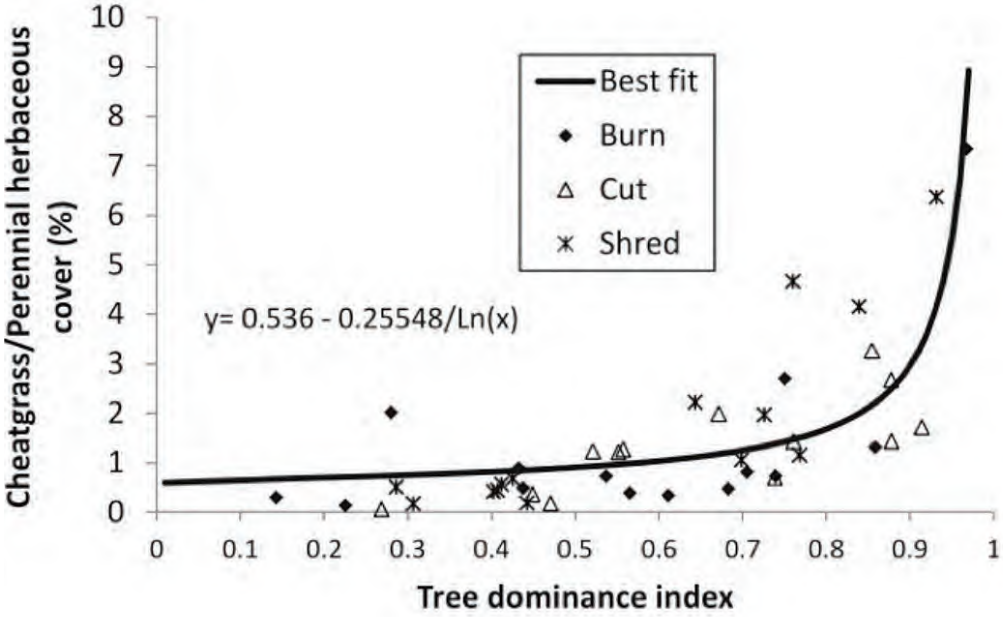

Figure 5-18—Ratio of cheatgrass to perennial herbaceous cover in relation to pretreatment tree dominance index (TDI) for burn, cut, and shred tree control treatments at Scipio, Utah (r^2 = 0.64) (Roundy et al. 2014a).

Soil moisture and temperature regimes are also linked to the magnitude of increase in invasive annual plants. Invasive annual cover 3 years after cutting was greater than adjacent untreated plots across multiple sites in the Great Basin (Miller et al. 2014b). However, there were distinct differences between warm and dry and cool and moist sites. Invasive annual cover was less than 5 percent on cut cool and moist ecological sites compared to 18 percent on the warm and dry sites (Miller et al. 2013). Roundy et al. (2014) reported cheatgrass cover remained low (below 6 percent) after cutting on multiple cool sites across the Great Basin. However, cheatgrass cover on warmer sites increased significantly from 19–27 percent after cutting treatments. Across 17 sites in the Great Basin, locations with warmer fall temperatures were especially susceptible to cheatgrass dominance, while those with cooler falls and relatively wet winters and springs were more resistant because they more frequently supported higher perennial herbaceous dominance (Roundy et al. 2018).

Within treatment sites, increases in cheatgrass cover can be greater beneath dropped trees and in tree-litter mats that result in mortality of perennial grasses from heavy shading (Bates et al. 2007a). Few long-term studies have followed the persistence of invasive annuals following treatment. In a 13-year study, cheatgrass cover generally remained less than 5 percent following cutting, but cover varied with precipitation and reached 15 percent cover in a year when precipitation was 200 percent of average (Bates et al. 2005).

Although cutting often results in increased invasive annual abundance, the increase is usually less than that following prescribed burns (Miller et al. 2014b; O'Connor et al. 2013; Roundy et al. 2014a; Williams et al. 2017). Cut-pile-burn can also result in large increases in invasive plants, resulting from high mortality of perennial grasses directly beneath the pile and large increases in nitrogen. In northern Arizona, treatment by burning slash piles resulted in a 50-fold increase in soil ammonium concentrations and a 20-fold increase in nitrate (Covington et al. 1991). The increases in inorganic nitrogen disappeared in 5 years. On 11 conifer-encroached sagebrush sites across the Great Basin, cheatgrass and exotic forbs increased after cutting and fire, but the increase was slightly more than 1.5 times greater in burned than cut sites (Miller et al. 2014b). On cool and moist ecological sites, invasive annual cover remained below 5 percent—but was more

than 30 percent on burned and 18 percent on cut warm and dry ecological sites (Miller et al. 2013). In this same regional study, cheatgrass and nonnative annual forb cover were similar on untreated and cut plots by the sixth posttreatment year but remained greater on burned pretreatment sites where tree dominance was high (Williams et al. 2017). Low levels of cheatgrass and nonnative forb cover were associated with higher tall grass cover on cut plots or on burn plots at lower pretreatment tree dominance.

Chemical Treatment

Widespread herbicide uses on rangelands did not occur until after World War II. Even then, use of herbicides to kill pinyon and juniper was primarily experimental, and no herbicides were registered for use on grazing lands by the Environmental Protection Agency until 1975 (Evans et al. 1975). The majority of herbicide research related to pinyon and juniper was conducted in the Colorado Plateau and northern Arizona, with few herbicide studies completed in the Great Basin. Possibly the earliest herbicide studies on pinyon and juniper were investigations on foliar applications of arsenite in the early 1940s (Parker 1945), which was never registered for use on grazing lands (Evans et al. 1975). Herbicides tested in the 1950s and ’60s had mixed results with respect to tree-kill and understory response—and most never became management tools (Evans et al. 1975; Johnson 1967). By the 1970s, Picloram™ and Tebuthiuron™ showed some promise for juniper control. Picloram™ is a systemic herbicide used to control woody plants and broad-leaved forbs, which can be sprayed, injected, applied to cut surfaces, or applied to the soil near plant roots. Tebuthiuron™ is a broad-spectrum systemic herbicide used to control herbaceous and woody plants. It is usually applied to the soil near plant roots. The morphology of juniper, including dense canopies, thick leaf cuticles, and stomates on the underside of leaf scales (fig. 2-16b), make them relatively resistant to foliar chemical application (Johnson 1967; Miller and Shultz 1987). Soil herbicide applications had greater control potential because of the extensive, shallow root systems of pinyon and juniper (Young et al. 1984). In the early stages of the transition of western juniper into sagebrush communities, spot treatment or basal bark application of Picloram™ resulted in 90–98 percent mortality of small trees (Sbatella and Twelker 2013). This would also support the effectiveness of spot treatment following mechanical control. Spring application of a mixture of Tordon™ (Picloram), Milestone™ (aminopyralid), and the surfactant Alligare 7™ was also effective in killing trees of less than 4 inches with 100 percent mortality, and trees 4–12 inches with 98 percent mortality (Monument Soil and Water District 2017).

Responses to Chemical Treatment

In the early 1960s, Picloram™, an herbicide with both foliar and soil applications, was tested in both spray and pellet form in the eastern United States (Watson and Wiltse 1963; Wiltse 1964). It showed promise for control of juniper in the West (Johnson 1967). Picloram™ is nontoxic to mammals but persists in the environment. It is not strongly absorbed by soil colloids, which allows it to move freely in water (Evans et al. 1975), raising concerns about potential contamination in runoff from treated watersheds (Johnson 1967; Vallentine 1971). Typically, only limited amounts (less than 1 pound per acre) is applied for woody plant control. In the late 1970s and early 1980s, Tebuthiuron™ was another herbicide evaluated for juniper and pinyon control (Johnsen and Dalen 1990; Van Pelt and West 1993). However, cool season perennial grasses are sensitive to relatively low rates, resulting in greater mortality compared warm season grasses. There are also concerns about Picloram’s™ longevity and the potential for contamination in groundwater.

Since the 1970s, a combination of Picloram™ and Tebuthiuron™ have been commonly used, especially with mechanical treatments for pinyon and juniper control. Both often

have mixed results when used alone. They can be effective following mechanical tree removal when applied selectively on small trees (Young and Evans 1976) or on stumps with live limbs. In western Nevada, Picloram™ was used following chaining to kill small sapling trees (Young and Evans 1976). Although the followup treatment resulted in greater herbaceous production, the increase in biomass was largely from cheatgrass—even though crested wheatgrass was present on the site.

Several studies report large increases in annual invasive grasses following control of pinyon and juniper (Evans and Young 1985; Roundy et al. 2014a; Young and Evans 1976; Young et al. 1985). In all cases, resistance to invasive annuals was low due to severely depleted native perennial grass and forb communities and in sites where soil moisture temperature regimes were warm and dry. On these sites, the increase in soil moisture and nitrogen following tree removal were quickly exploited by invasive annuals already on the site and in the soil seed bank. The most common use of herbicides associated with tree removal is for posttreatment control of invasive annuals on low-resistance ecological sites. The most commonly used herbicides for invasive annual control following pinyon and juniper treatment is Imazapic (Plateau)™.

Prescribed Fire

Prescribed fire was little used in the first few decades following World War II (fig. 5-19). In the early part of the 20th century, many ecologists supported the active suppression of fire, a European philosophy that spilled over to the management of plant communities in North America (Wright and Bailey 1982). But early in the 1900s, some people, including Leopold (1924), recognized the importance of fire for ecosystem health. The Leopold Report of 1963 (Leopold 1963) reported that fire prevention could lead to an accumulation of fuels as well as changes in plant community composition and structure. Some of the earliest research on prescribed fire in pinyon and juniper woodland was conducted on the Hualapai Indian Reservation in northwestern Arizona in 1953, when an experimental prescribed fire escaped and burned 16,000 acres (Arnold et al. 1964; McCulloch 1969; Schroeder 1966). After additional prescribed burning and monitoring over the next 11 years, Schroeder (1966) concluded that burning of mature pinyon and juniper woodland was only successful during peak fire weather conditions, which occurred only a few days a year—and in some years never occurred. He found that woodlands with higher proportions of pinyon carried fire better than stands with higher proportions of juniper.

In possibly the first synthesis on burning pinyon and juniper woodlands, Blackburn and Bruner (1975) concluded results of these early studies were mixed and generally focused on the postfire response of perennial grasses. They suggested that widespread use of prescribed fire was limited by "the extremely hazardous burning conditions necessary to treat such large areas and the fact that the Grand Canyon is not available to everyone for a firebreak," (as exists on the Hualapai Indian Reservation). The required extreme weather conditions discouraged land managers from using prescribed fire. Burning mature pinyon and juniper stands with little understory was found to be extremely difficult, requiring hazardous weather conditions and/or pretreatment to increase fuel continuity (Arnold et al. 1964; Aro 1971; Wright et al. 1979). Federal and State agencies were hesitant to use prescribed fire for fear of escaped fires. By the early 1970s, prescribed fire treatments on Federal lands were uncommon (Aro 1971). But following an evaluation of 50 sites across the Colorado Plateau, Aro (1971) recommended the use of burning rather than mechanical treatments where fuels were adequate to carry fire. The presence of adequate fuels and significant increases in postfire perennial grasses reported by Aro (1971) strongly suggests these sites had an adequate abundance of preburn perennial

Figure 5-19—In the early part of the 20th century, many ecologists supported the active suppression of fire, a European philosophy that spilled over to the management of plant communities in North America. But early in the 1900s, Leopold recognized the importance of fire for ecosystem health. Northcentral Oregon. (Photo by Rick Miller, Oregon State University.)

grasses to recover after the fire. In the 1970s and ’80s, acres treated with prescribed fire increased throughout the Intermountain West. Between 2002–2016, 5.5 million acres were prescribed burned across public lands in Oregon, Idaho, California, Nevada, Utah, Colorado, and Arizona (National Interagency Fire Center 2018), which accounted for 12 percent of the total area burned across these states over the same period.

Responses to Fire

Today the increasingly overwhelming problem of invasive annual plants across the Intermountain Region requires cautious consideration when deciding to use prescribed burning treatments. To predict postfire vegetation response, important considerations are prefire vegetation, ecological site characteristics, and potential fire severity, all of which affect resilience and resistance to invasive annuals (table 5-3; figs. 5-2, 5-19) (Chambers et al. 2016a; Dhaemers 2006; Miller et al. 2013, 2014a, 2015; Roundy et al. 2018; Urza et al. 2017). Tree dominance at the time of treatment can also have a significant impact on understory plant composition and fire severity (Bates et al. 2011; Roundy et al. 2014a; Williams et al. 2017).

Tree Mortality and Fire Severity

Tree mortality in burned pinyon and juniper stands is a function of fire weather and fuels, which includes wind speed (and/or slope), relative humidity, air temperature, tree size, and moisture content—as well as fuel structure, abundance, and continuity (Martin 1978; Wright et al. 1979). One of the primary advantages of burning is the high mortality of small trees, which are often missed during mechanical treatments and require followup (Arnold et al. 1964; Dwyer and Pieper 1967; Jameson 1962; Martin 1978). Prescribed fire easily kills trees less than 4 feet tall even under relatively mild to moderate weather

conditions. However, mortality of trees over 6 feet tall is often less than 70 percent, except under extreme fire weather conditions (fig. 5-20; Dwyer and Pieper 1967; Martin 1978; Wright et al. 1979) or when sufficient surface and ladder fuels are present, like those occurring in Phase I and early Phase II woodlands where understories are intact (Miller et al. 2013).

There is a geometric decrease in fire intensity with the decline in percent cover and height of sagebrush, which are important ladder fuels (fuels that connect the surface fuels to the tree canopy) in pinyon and juniper woodlands (fig. 5-21; Brown 1982). The

Table 5-3—Advantages and disadvantages of different vegetation treatment methods commonly used on pinyon and juniper woodlands.

Method	Advantages	Disadvantages
Chemical	Effective as a spot treatment on small trees or on stumps with remaining basal branches following mechanical treatments.	Mixed results when used alone.
Chaining	Improved establishment of broadcast seeding between double chaining. Majority of studies reported increases in perennial grasses when seeded. Chain + seeding decreases runoff and sediment loss.	Misses the small trees requiring a follow-up treatment. Some studies have reported increases or no change in runoff or sediment production, which is closely linked to posttreatment herbaceous cover. Limited by steep topography. Expensive.
Windrowing	Increases mortality and life of treatment compared to chaining. Invasive annual increase usually less than following prescribed fire.	Expensive and increases soil surface disturbance. Usually requires seeding.
Shredding	Minimal impact on shrubs and biological crust. Decreases bare ground. Compaction of fine fuels reduces the hazard for wildfire.	Tire compaction increases runoff and sediment yield on about 15 percent of the treatment area however compensated by decrease in bare ground. Potential for a small to moderate increase in invasive annuals. Mulch depths of > 5 m can inhibit emergence of perennial grasses. Misses small trees.
Hand Cutting	Minimal impact on shrubs and biological crust layer. Minimal surface disturbance. Invasive annual increase usually less than following prescribed fire. Wide seasonal window. Usually a first-year increase in perennial grasses and forbs. Decreases bare ground especially with lop-and-scatter. Costs are low in phase I.	Leaves large amounts of slash when treating mid and late phase II and phase III. Significantly increases 1- and 10-hr surface fuels in the first 3 years. Heavy slash can have a smothering effect resulting in mortality of perennial herbage. Cost are high in phase III and require follow-up treatment of slash. Potential for a small to moderate increase in invasive annuals. Misses small trees.
Prescribed Fire	Treat large areas usually at lower cost than other methods. Effective in killing small trees. Removes slash, especially important in late phase II and III. Usually results in an increase in residual perennial herbs in the second or third postfire year.	High impact on nonsprouting shrubs. Usually results in the highest increase in invasive annuals although the magnitude of response is closely linked to ecological site characteristics and preburn plant composition. Narrow seasonal window of application and weather conditions can be unpredictable on proposed dates of ignition. Pretreatment deferment from grazing to allow for accumulation of surface fuels. Pretreatment of fuels often required in late phase II and III. High fire severity can result in > 50 percent mortality of perennial grasses. Temporary increase in wind and water erosion dependent on recovery of vegetation cover. Can have a high impact on biological crusts, with moderate to high severity fires.

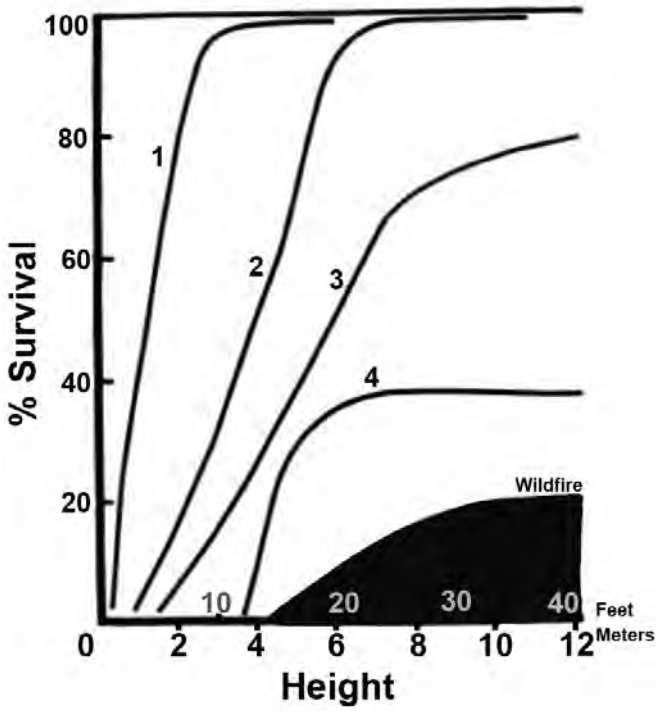

Figure 5-20—First year survival of western juniper in juniper-sagebrush-bunchgrass communities following four prescribed burning conditions; winds 5 to 12 mph, and conditions: (1) 70 ˚F, RH 25 to 30 percent; (2) 70 to 85 ˚F, RH 25 to 30 percent: (3) 75 to 85 ˚F, RH 18–20 percent; and (4) 80 ˚F, RH 10 percent. Under conditions 1 and 2, survival of larger juniper was nearly 100 percent, whereas 73 and 37 percent of the larger trees survived the more severe conditions of 3 and 4. Wildfire conditions resulted in 20 percent or less tree survival (Martin 1978).

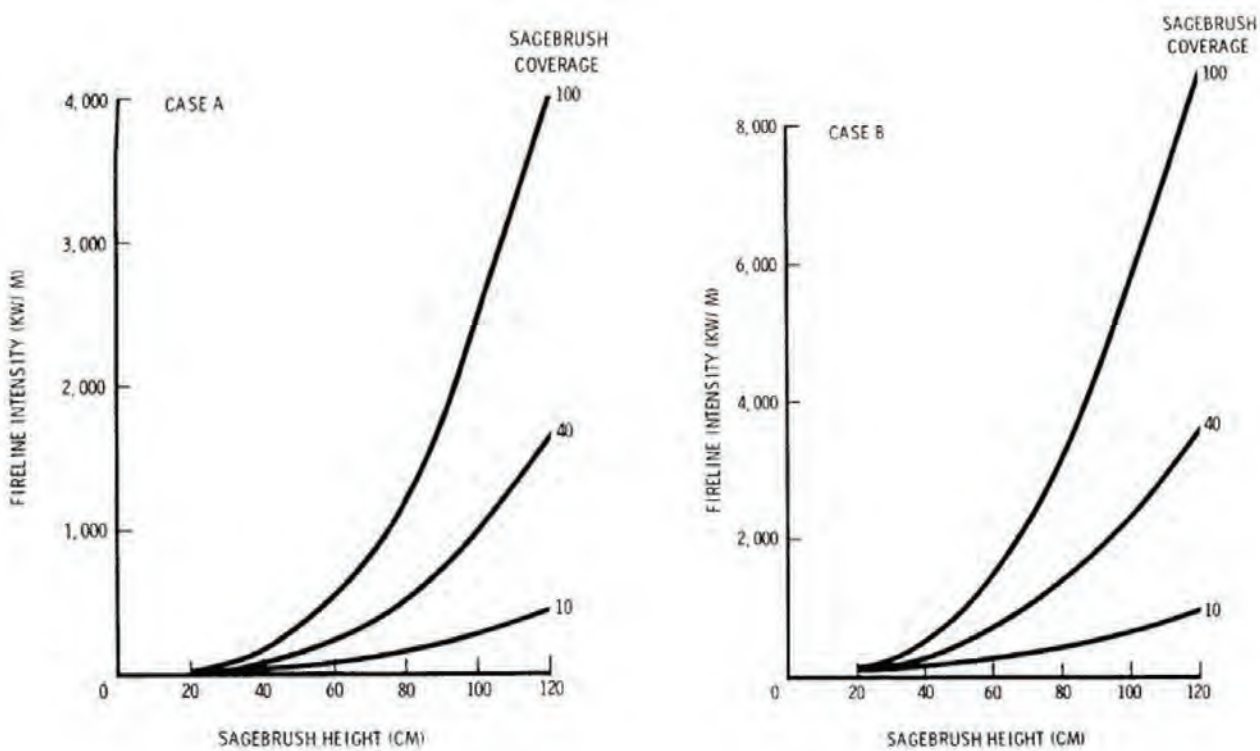

Figure 5-21—Fireline intensity at 8-mi/h midflame-height windspeed and 900 pounds per acre of grass and forbs. (A) Grass and forbs are 57 percent alive and sagebrush entirely alive. (B) Grass and forbs are entirely dead and sagebrush foliage is one third dead (Brown 1982). Fireline intensity is the rate of energy released per unit length of fire front (units kilowatts/meter).

proportion of dead surface fuels also significantly influences intensity. As woodlands mature, height and cover of sagebrush and other shrubs, necessary to support crown fires under moderate weather conditions, decrease as does fine surface fuel abundance and continuity necessary for the spread of surface fires. As understory fuels decline, increased wind speeds, higher temperatures, and decreased relative humidity are required for successful burning, but these conditions can result in higher intensity and potentially greater severity fires. Grazing may also be deferred to allow for the accumulation of fine fuels for successful application of fire (Arnold et al. 1964; Humphrey 1962).

Wright et al. (1979) reported that successful prescribed burning of late Phase II and III woodlands without prior treatments requires air temperatures of 95 to 100 ˚F, low relative humidity, and wind speeds of between 8–20 mph, although minimum wind speeds of 3 mph have been reported to successfully carry fire (Dicus et al. 2009; Martin 1978). Unstable atmospheric conditions also increase the spread of fire by influencing convection, which is the primary means of heat transfer in wildfires. Wind speeds required for successful burning depend on topography and fuel sizes, abundance, structure, continuity, and moisture content. To burn mature woodlands with low amounts of understory fuels (e.g. Phase III) during moderate weather conditions, pretreatments such as tree cutting a portion of the tree overstory to add surface fuels can be done the fall or winter prior to burning (fig. 5-22; Bates and Svejcar 2009; Bates et al. 2011). In woodlands with 40–60 percent tree canopy cover, cutting 25 percent of mature trees in the fall or winter prior to burning was adequate to kill the majority of remaining trees under moderate fire weather conditions (Bates et al. 2011).

Shrub Response to Fire

One of the biggest concerns managers have with burning Phase I and Phase II pinyon and juniper woodlands is the temporary loss of nonsprouting, fire intolerant shrubs such as sagebrush (Davies et al. 2014; Miller et al. 2000; Roundy et al. 2014a). Recovery of the shrub canopy to 20–30 percent cover on cool and moist mountain big sagebrush communities usually takes 20–35 years following a fire (Barney and Frischknecht 1974; Bunting et al.

Figure 5-22—When burning a Phase II or III woodland it is often necessary to cut a portion of the trees in the fall prior to burning to increase surface fuel loads. This also allows the burn to be conducted under less severe weather conditions. Steens Mountain, eastern Oregon. (Photo by Rick Miller, Oregon State University.)

1987; Lesica et al. 2007; Miller and Heyerdahl 2008; Moffet et al. 2015; Nelson et al. 2014; Ziegenhagen 2003; Ziegenhagen and Miller 2009).

In complex, patchy burns where a big sagebrush seed source remains after a fire, recovery can occur within 9–15 years (Pyle and Crawford 1996; Ziegenhagen 2003). However, in high-severity burns in late Phase II and Phase III woodlands, big sagebrush seed is often unavailable because of the scarcity of mature plants in the prefire understory and/or combustion and mortality of seed in the seed bank. Following high-severity fires in Phase II and III woodlands, big sagebrush recovery comes from an outside seed source or artificial seeding (Davies et al. 2014). Persistence of the postfire shrub layer once reestablished depends on the rate of conifer reestablishment and growth (fig. 5-15; Johnson and Miller 2006). In west-central Utah and northeastern California, sagebrush was the dominant woody layer 30–60 years following fire but declined to less than 1 percent cover on burns 80–100 years old as a result of increasing juniper dominance (fig. 5-23; Barney and Frischknecht 1974; Miller and Heyerdahl 2008). Aspect, as it relates to temperature and moisture, also influences big sagebrush establishment, which is generally more rapid on the

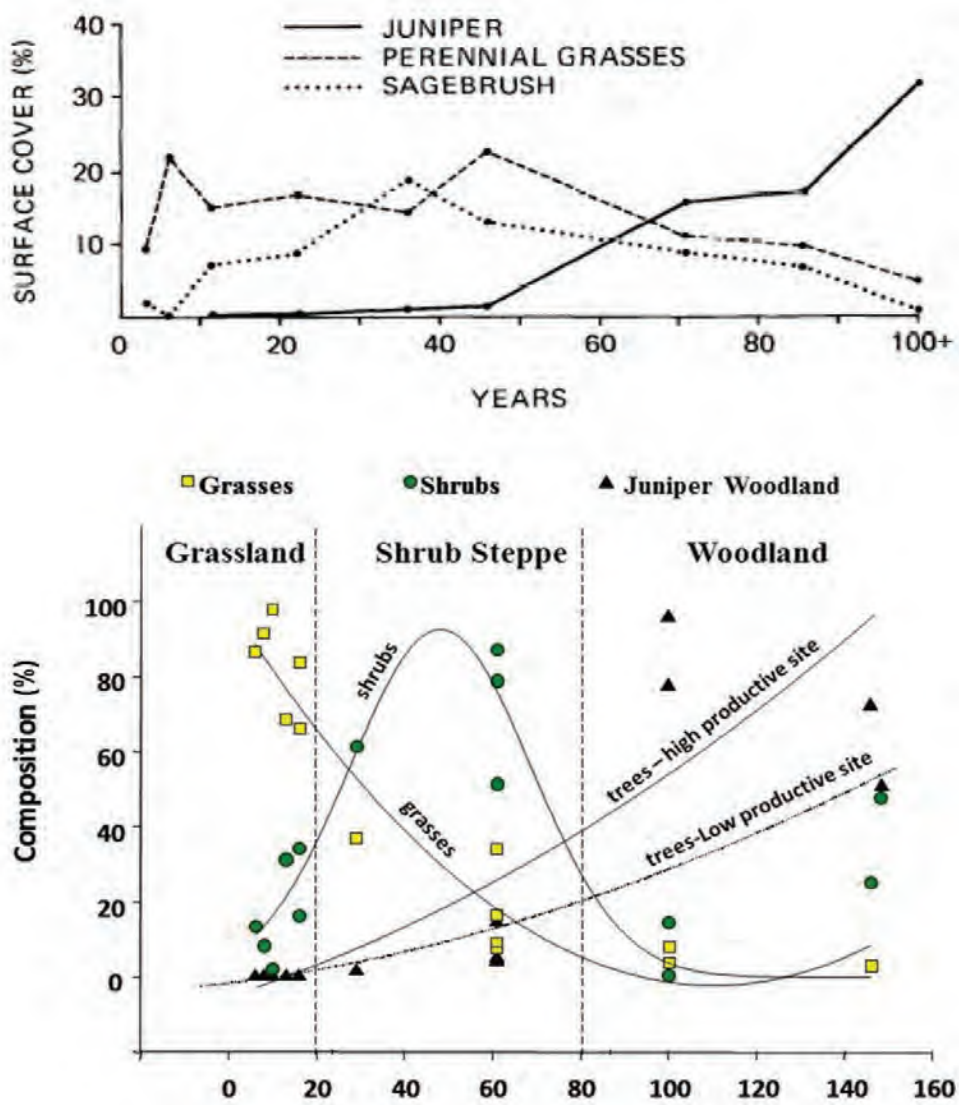

Figure 5-23—Plant succession models following fire for (A) surface cover of juniper, perennial grasses and sagebrush by age of fire in west central Utah (Barney and Frishknecht 1974); and (B) percent composition based on plant cover in cool/moist mountain big sagebrush in northeastern California (Miller and Heyerdahl 2008).

cool and moist versus warm and dry sites (Chambers et al. 2017; Davies and Bates 2017). Postfire recolonization of Wyoming big sagebrush is typically very slow to nonexistent (Miller et al. 2013). Wyoming big sagebrush cover 18–25 years following fire was less than 5 percent (Lesica et al. 2007; West and Yorks 2002).

Bitterbrush is a weak resprouter (Nord 1965), and its postfire sprouting and persistence are highly variable due to differences in genetics, soil site characteristics, soil moisture conditions, fire severity, and the age and phenology of plants at the time of burning (Blaisdell and Mueggler 1956; Clark et al. 1982; Cook et al. 1994; Nord 1959, 1965; Riegel et al. 2006). Residual seed in the soil depends on prefire seed input and fire severity and is likely scarce in Phase III woodlands. An important mechanism of bitterbrush seedling establishment is dispersal and caching by rodents (Nord 1965; Sherman and Chilcote 1972; Vander Wall 1994; West 1968), which typically occurs within 80 feet of the mother plant (Vander Wall 1994). Mountain mahogany is also fire sensitive and a weak postfire resprouter. Four years following a cut-and-broadcast burn, mountain mahogany cover and density declined from 8 percent to less than 1 percent and 71 to 30 plants per acre, respectively (O'Connor et al. 2013). In adjacent stands that were only cut, mountain mahogany cover was unchanged from pretreatment levels but density increased from 71 to 162 plants per acre in the fourth posttreatment year.

Common resprouting shrubs, green and grey rabbitbrush, and snakeweed are consistently found in recently burned areas (Barney and Frischknecht 1974; Wright et al. 1979). However, their abundance depends on prefire vegetation composition, fire severity, and posttreatment management (Miller et al. 2013). They can establish rapidly in open areas where competition from other perennials is low (Barney and Frischknecht 1974). Green rabbitbrush and snakeweed presence often increases following fire and can remain abundant for 10–36 years, at which point they begin to decline in the absence of frequent disturbance (Barney and Frischknecht 1974; Harniss and Murray 1973; Young and Evans 1974). Green rabbitbrush is a tap-rooted species and is short-lived and less competitive than big sagebrush (which has a lateral root system). Seedling density, flower production, and shoot growth of green rabbitbrush decline as competition from other species increases (McKell and Chilcote 1957; Young and Evans 1974). Snakeweed is also a relatively short-lived (20 years) tap-rooted species (Mozingo 1987; USU Ext 2016). Grey rabbitbrush is more sensitive to fire severity, sprouting from stems rather than the base as green rabbitbrush and snakeweed do (Wright et al. 1979).

Fire and Perennial Grasses

More than 80 percent of studies evaluating plant response following prescribed fire in sagebrush ecosystems across the Great Basin reported that the cover of native deep-rooted perennial grasses declined the first year following a fire—but recovered to or above preburn levels by the second or third year (Miller et al. 2013). In no study did perennial grass cover increase in the first year postfire. In contrast, cut-and-leave treatments without burning resulted in an immediate increase in perennial grass cover (Miller et al. 2014b; O'Connor et al. 2013; Roundy et al. 2014a; Williams et al. 2017). This pattern of first-year decline followed by recovery of deep-rooted perennial grasses is common in sagebrush ecosystems throughout the Great Basin (Bates and Svejcar 2009; Bates et al. 2011, 2014; Dhaemers 2006; Miller et al. 2014b; O'Connor et al. 2013; Roundy et al. 2014a; Williams et al. 2017). In 11 conifer expansion sites across the Great Basin, tall perennial grass cover declined 35 percent in the first postfire year but was 146 percent greater than unburned sites in the third postfire year (Miller et al. 2014b). By the third and fourth years, herbaceous cover and density were similar to cut treatments (Miller et al. 2014b; O'Connor et al. 2013). However, sagebrush encroached communities with high tree dominance (Phase III) typically had lower understory vegetation response compared to communities with lower tree dominance

(Dhaemers 2006; Williams et al. 2017). Perennial grass abundance typically peaks within the first 10 postfire years and can remain an important component of the plant community for 20–35 years following fire, after which gradual declines are likely (fig. 5-23; Barney and Frischknecht 1974; Miller and Heyerdahl 2008).

Increased cover of perennial grasses in the early postfire years is generally due to increased plant size rather than increased plant density (fig. 5-24a; Bates et al. 2009, 2011; Everett and Sharrow 1985a,b; Miller et al. 2014b). Increased growth during the first 3 postfire years is associated with the longer period of soil water availability and increased nutrients resulting from the reduction of trees (Bates et al. 2000; Roundy et al. 2014b). Increases in the density of perennial grasses do not typically occur until 3 or more years following fire (Bates et al. 2011; O'Connor et al. 2013; Williams et al. 2017). Therefore, the occurrence and relative abundance of prefire perennial vegetation is more important to early and mid-succession than the soil seed bank (fig. 5-24b; Allen et al. 2008b; Everett and Sharrow 1985a; Everett and Ward 1984; Koniak and Everett 1982; Pekas 2010).

In addition to prefire understory plant composition and tree dominance, fire intensity can have a significant impact on perennial grass recovery (fig. 5-25). Low- to moderate-intensity fires with limited duration generally produce minimal perennial grass mortality (Miller et al. 2014b). However, high intensity and/or longer duration fires in late Phase II and III woodlands resulted in mortality rates above 50 percent (O'Connor et al. 2013) and as much as 85 percent mortality (Bates et al. 2011). A high-severity fire in Phase III woodlands reduced perennial bunchgrass cover from 5 percent to less than 1 percent (Bates et al. 2014). Nine years after the fire, cover had increased to near preburn levels. High mortality can mean slow postfire recovery and low resistance to invasive annuals. In adjacent burned Phase II woodlands, pretreatment perennial bunchgrass cover was 10 percent and declined to nearly 2 percent in the first year following fire, but 9 years later increased to nearly 20 percent, compared to only 5 percent in Phase III. Although mortality was considerable in both phases, the density of perennial bunchgrasses in Phase II the first year following fire was nearly 4 plants per 10 square feet compared to less than 1 plant per 10 square feet in the Phase III woodland. Unfortunately, limited work has investigated the number of deep-rooted perennial grasses required for recovery, which varies with ecological site factors, especially soil water and temperature regimes.

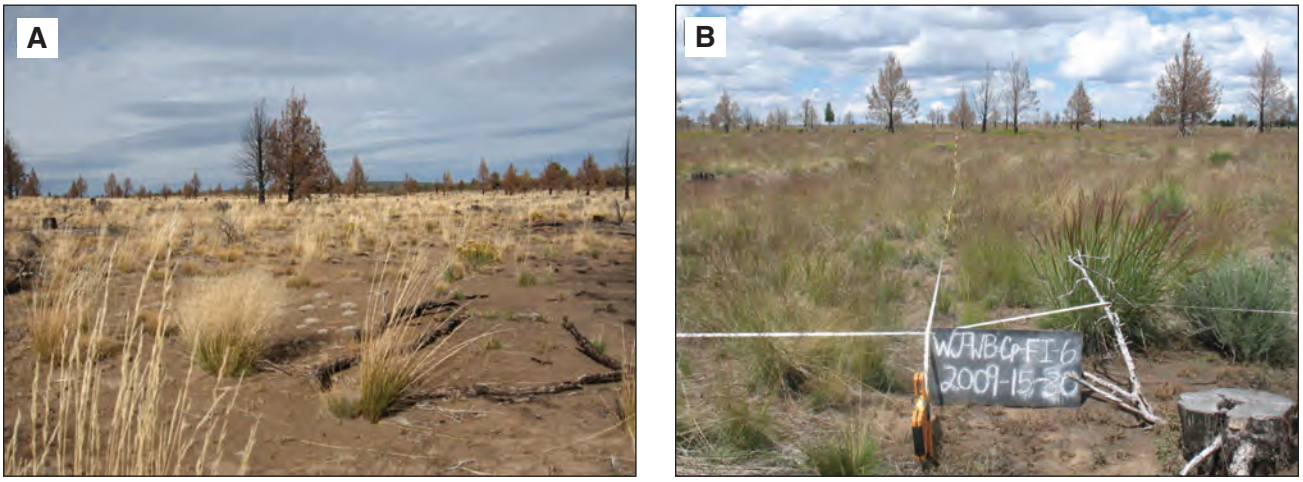

Figure 5-24—Prescribed burn in cool/moist mountain big sagebrush/Idaho fescue community in Phase I and early Phase II in postburn years (A) 1 and (B) 3. Prior to the burn there was a high mortality of sagebrush from an Aroga moth infestation. Central Oregon. (Photo by Rick Miller, Oregon State University).

Figure 5-25—This high severity wildfire is made evident by 90 percent consumption of surface organic matter, few remaining shrub skeletons, consumption of tree needles and bark, and high mortality of perennial grasses, if they were present prior to the burn. High fire severity in this Phase II mountain big sagebrush woodland (a 12- to 14-inch precipitation zone on frigid soils bordering on mesic) was the result of high temperatures, winds, and low humidity. The advantage and disadvantage of high severity fires is the consumption of both native and invasive seed pools, which provides a 1-year window of low competition from invasive annuals, increasing the potential for successful seeding. Central Nevada. (Photo by Jeanne Chambers, USDA Forest Service.)

Fire and Perennial Forbs

The response of perennial forbs to prescribed fire in sagebrush and pinyon and juniper ecosystems is highly variable (Bates et al. 2017a) and closely linked to soil moisture and temperature regimes and pretreatment composition (Miller et al. 2013). Most studies reporting no postfire response for perennial forbs occurred on warm and dry (mesic/aridic) ecological sites. In contrast, increases were reported for 70 percent of prescribed fire studies on cool and moist (frigid/xeric) ecological sites. A rapid increase of perennial forb abundance typically occurs in the first few postfire years (Bates et al. 2011; Bates and Svejcar 2009; Dhaemers 2006; McCulloch 1969; Miller et al. 2014b; Roundy et al. 2014a; Stager and Klebenow 1987). Where fires were low- to moderate-severity, difference in perennial forbs between burned and control plots 3 years following treatment ranged from none in early Phase I (TDI = 0), 2.5-fold in late Phase II (TDI =.6), and more than 5-fold in Phase III (TDI = more than 0.9) (fig. 5-17; Roundy et al. 2014a). However, abundance often decreases to preburn levels 4-10 years following fire (Bates and Svejcar 2009; Bates et al. 2014). Increases in the postfire abundance of perennial forbs were often greater on sites where pretreatment perennial grass abundance was low (Everett and Ward 1984; Roundy et al. 2014a) or where high-severity fire resulted in high perennial grass mortality (Bates et al. 2011). Perennial forb abundance following fire also increased along an elevation gradient of decreasing temperatures and increasing moisture (Dhaemers 2006; Urza et al. 2017). The season of available green forb abundance was also longer in burned

compared to unburned plots (Wrobleski and Kauffman 2003), as a result of a longer season of increased soil water availability (Bates et al. 2000; Roundy et al. 2014a).

Invasive Annual Plant Response to Fire

Increases in invasive annual plant abundance is frequently greater following fire as compared to mechanical treatments (figs. 5-17, 5-26), especially on warm and dry sites (Barney and Frischknecht 1974; Dhaemers 2006; Koniak 1985; Miller et al. 2013, 2014a; Roundy et al. 2014a). The increased response of invasive plants after fire is associated with an immediate initial decrease in perennial grasses and increased available soil nutrients, especially nitrogen (Miller et al. 2013). Fire also increases potential germination of cheatgrass by as much as threefold more than cutting or shredding by increasing seedbed water and temperature conditions, which enhances cheatgrass (Cline et al. 2018; Roundy et al. 2017, 2018). Cover of invasive annual grasses and forbs often increase in the early postfire years and then can later decline to preburn levels (Barney and Frischknecht 1974; Bates et al. 2011, 2014; Dhaemers 2006; Everett and Ward 1984; Koniak 1985; Miller et al. 2014b; Roundy et al. 2014a). However, significant increases that persist for 25 years or more have also been reported (Bates et al. 2014; Chambers et al. 2017; Urza et al. 2017). Persistence and dominance of invasive annuals is often a function of several factors, including depleted perennial plant cover at the time of the fire, fire severity (which when high often results in high perennial plant mortality), postfire management, ecological site characteristics, and pretreatment tree dominance (Miller et al. 2013; Roundy et al. 2014a). Roundy et al. (2018) found that the negative relationship between perennial herb (mainly perennial grass) and cheatgrass cover varied from weak to strong among 17 sagebrush sites on untreated, burned, and mechanically

Figure 5-26—Fire is a useful tool, but the threat of invasives following a burn is of major concern. Increases in invasive annuals following a fire is often greater than following cutting and shredding treatments. Site characteristics—including moisture and temperature regimes—and surface vegetation present on the location prior to treatment are key components that influence resistance to invasive plants in addition to fire severity. Egan Range, Nevada. (Photo by Rick Miller, Oregon State University.)

treated plots. Differences in seasonal soil temperature and available water explained 71 percent of the variation in perennial grass cover and 69 percent of the differences in cheatgrass cover among sites 6 years after prescribed fire. Drier falls and wetter winters and springs favored perennial herb cover while wetter and warmer falls and warmer late springs favored cheatgrass cover.

Pretreatment cover of conifers and perennial bunchgrasses is also closely related to the postfire response and persistence of cheatgrass, especially on sites with low resistance (Bates et al. 2014; Roundy et al. 2014a; Williams et al. 2017). Six years after fire, cheatgrass cover was still higher on burned than unburned and cut plots at mid- to high-pretreatment TDI (Williams et al. 2017). But cheatgrass cover on burned plots varied greatly among sites. The combination of low preburn perennial grass abundance and high fire severity in Phase III woodlands resulted in significantly less posttreatment perennial grasses and greater cheatgrass abundance in Phase III compared to Phase II woodlands (Bates et al. 2014). In Phase III woodlands, cheatgrass cover increased from a trace to nearly 40 percent 4 years after fire and remained higher than 30 percent 9 years after fire. The high-severity fire in the Phase III woodland resulted in a decline in perennial grass cover from less than 5 percent to less than 1 percent and pretreatment density from 4 to less than 1 plant per 10 square feet in the first year following fire.

In Phase II, woodlands where perennial grass density and cover were greater after fire because of lower fire mortality, cheatgrass cover remained below 10 percent and declined to less than 5 percent 9 years after fire. The large amount of variation across ecological sites in both time and space makes it difficult to pin down the abundance of perennial grasses necessary for recovery and to limit persistent increases in invasive annuals following disturbance. However, limited studies indicate that a minimum of two to three (or possibly three to four) deep-rooted perennial grasses per 10 square feet are needed for recovery of the native perennial grass layer (Bates et al. 2007a, 2014; O'Connor et al. 2013). Type of burn treatment can also influence the magnitude of cheatgrass response. In a relatively cool and moist sagebrush-mountain mahogany community, a broadcast burn in cut western juniper stands resulted in greater cheatgrass increases than in pile-and-burn treatments (O'Connor et al. 2013). However, cover of cheatgrass was less than 6 percent across all treatments.

Postfire Tree Regeneration

The rate of postfire tree recruitment depends on tree survival, residual and outside seed sources, ecological site characteristics, and postfire management. Immediately following fire, there can be a lag in tree establishment due to the loss of shrubs, which act as nurse plants (Burkhardt and Tisdale 1976; Chambers 2001; Erdman 1970; Wangler and Minnich 1996). Shrubs provide desirable microsites for tree establishment (Burkhardt and Tisdale 1976; Everett and Ward 1984; Meagher 1943; Miller and Rose 1995; Phillips 1909), especially for drought susceptible pinyon seedlings (Bristow et al. 2014). Shrubs also provide perching sites for avian seed dispersers (Chavez-Ramirez and Slack 1994). Recruitment of singleleaf pinyon pine and Sierra and California junipers along the east slopes of the Sierra Nevada in southern California was very slow in the first 25 years postfire but accelerated in the following 15 years (Wangler and Minnich 1996). Others have reported that during the first 50 years, postfire recruitment was greater for Utah juniper than singleleaf pinyon in Nevada (Tausch and West 1988).

But after 60 years, singleleaf pinyon recruitment exceeded that of Utah juniper. In southeast Oregon and southwest Idaho, development of western juniper woodlands from initial tree establishment to tree dominance (Phase I to Phase III) varied from 60 to 80 years on cool and moist ecological sites to more than 125 years on warm and dry ecological sites (fig. 5-15; Johnson and Miller 2006). In Utah and northeast California,

pinyon and juniper woodlands were well-developed 80–90 years after fire (Barney and Frischknecht 1974; Miller and Heyerdahl 1974). Others reported slower rates of postfire tree establishment. In central Nevada, tree cover was less than 1 percent in burned areas compared to 23.5 percent in adjacent chained areas 40 years after treatment (Bristow et al. 2014). In some cases, woodlands remained relatively open (11 percent cover) 115 years following fire (Stager and Klebenow 1987), possibly resulting from soil conditions or competition from understory vegetation. Once established, tree canopy growth of individual western and Utah juniper trees is relatively slow for the first 45–50 years, and then it increases during the next 50–70 years unless impacted by neighboring trees (Barney and Frischknecht 1974; Miller and Tausch 2001; Miller et al. 2005; Tausch and West 1988). Required retreatment cycles will vary with both site productivity and initial tree establishment. Once the area has an adequate density of tree seedlings to stock the area, woodland succession transitioning from Phase I to Phase II will take between 20–40 years and 60–120 years to transition from Phase II to Phase III (see fig. 2-2).

Response to Fire: Bare Ground and Litter

The proportion of bare ground increases immediately following fire but often decreases to near preburn levels 2–4 years after fire (fig. 5-24; Barney and Frischknecht 1974; Bates et al. 2009, 2011; Miller et al. 2014b). But with increased fire severity it can take longer for the percent cover of bare ground to return to preburn levels (Bates et al. 2014; O'Connor et al. 2013). Increased bare ground in the first postfire year occurs with the reduction of cover in vegetation, biological soil crusts, and litter. In Wyoming sagebrush and mountain sagebrush communities that have pinyon and juniper, low- to moderate-severity fires doubled the amount of bare ground from 30 percent prefire to 60 percent postfire in the first year (Miller et al. 2014b). Bare ground returned to near preburn levels by the second year after fire. In mountain big sagebrush communities, cover of bare ground in the first year increased from 20 percent to 40 percent in Phase II and 30 percent to 80 percent in Phase III woodlands following high-severity fires (Bates et al. 2011, 2014; O'Connor et al. 2013). Bare ground remained higher on burned than unburned plots in the third postfire year but declined to preburn levels within 6 years of the fire (Bates et al. 2014).

Litter cover is significantly reduced immediately following fire but typically returns to preburn levels within 2–3 years (Bates et al. 2011; Miller et al. 2014b). With more severe fires, however, litter recovery takes longer, often remaining below preburn levels for 4–9 years after fire (Bates et al. 2014; O'Connor et al. 2013). Little research has addressed the rate of recovery of litter biomass and depths following fire (Miller et al. 2013). Both litter biomass, depth, and cover influence ecosystem functions including surface soil temperatures and moisture (Young et al. 2013b). When litter abundance is sufficient to both increase and reduce soil temperatures and increase soil moisture, it can enhance seed germination and seedling establishment of desirable and nondesirable plants (Chambers 2000; Evans and Young 1970; Young et al. 2013a).

Fire and Seeding

During the early years of prescribed burning in pinyon and juniper, the goals of seeding were primarily about increased forage production and soil stabilization, and therefore introduced species were used. Schroeder (1961) reported that seeding grasses (crested and western wheatgrass, and weeping lovegrass) on burned sites for which grazing had been deferred for 3 years resulted in substantial increases in forage production reaching 1,660 pounds per acre. On the adjacent unburned area, forage production was only 60 pounds per acre. Between 1955 and 1963 on the Hualapai Indian Reservation in northwestern Arizona, forage production was increased by an average of 500 pounds per acre with burning and seeding treatments (McCulloch 1969). As

management goals began to consider wildlife (such as mule deer), rangeland revegetation trials began to seed native plants (Monsen et al. 2004; Plummer et al. 1968; Roundy 1996). Over time, emergency burned area rehabilitation plans evolved to emphasize the restoration of diverse, native plant communities. But success for seeding with native species has often been low, which allows cheatgrass and other introduced species to become established and dominant a site quickly. This at least partially due to the use of seed from inappropriate sources—and the rate of success is closely tied to soil moisture and temperature regimes.

Postfire seeding can be effective when treating pinyon and juniper stands where advanced infilling has left few residual perennial plants (Bybee et al. 2016). Successful postfire revegetation in these types of stands limits dominance by invasive annuals (Floyd et al. 2006; Redmond et al. 2014; Sheley and Bates 2008; Thompson et al. 2006). Seeding success after wildfire or prescribed fire in pinyon and juniper areas is highly dependent on species selection and seed source, seed placement, and posttreatment precipitation (Hardegree et al. 2016; Knutson et al. 2014; Monsen et al. 2004; Pyke et al. 2017; Roundy 1996; Roundy and Call 1988). Because pinyon and juniper expansion into sagebrush generally occurs in relatively higher precipitation zones compared to low elevation warm and dry big sagebrush sites, their potential for revegetation success is greater.

However, seeding success in woodlands bordering on occupying warm and dry sites can be expected to be lower. Postfire broadcast seeding is generally more successful when seeds are covered— drilling seed is usually more successful than broadcast seeding because it can place seed at the correct depth. However, postfire chaining is one method used to cover seeds following broadcasting (Juran et al. 2008; Monsen et al. 2004; Ott et al. 2003). Chaining may also help seedling establishment by breaking up water repellent soil layers, which can occur around the base of the tree (Madsen et al. 2015). Subsurface water repellency can prevent seedling roots from reaching deeper soil moisture and lead to seedling mortality (Madsen et al. 2012a,b). Although postfire chaining may initially reduce residual plant cover, it can improve establishment of broadcast seed sufficiently to prevent dominance by invasive annuals (Ott et al. 2003). One disadvantage of chaining is the reduction of biotic soil crusts, which can limit invasive plant dominance on some soils, especially in the Colorado Plateau (Evangelista et al. 2004). Broadcasting seed on snow has some benefits and has been observed to successfully establish seedlings (Meyer 1994). However, winter broadcasting (on snow, for two out of three sites) was less successful than fall broadcasting for Wyoming big sagebrush (Ott et al. 2017).

In the past, postfire seed mixes included primarily nonnative species, but recently mixes have included more or even exclusively native species. Some managers and researchers are concerned that introduced species in seed mixes often outcompete native species (Gunnell et al. 2010; Knutson et al. 2014; Vernon et al. 2001). But another, and perhaps more pressing concern, is taking advantage of the one opportunity to quickly establish a perennial herbaceous layer and prevent the establishment and dominance of invasive annuals. Planting sagebrush seed postfire has been considerably less successful than seeding perennial herbaceous species (Board et al. 2011; Davies et al. 2013; 2014; Knutson et al. 2014). Again, the appropriate seed source, seed application, and soil moisture conditions following planting are important factors determining success.

Knutson et al. (2014) suggested that, based on the success reported by McAdoo et al. (2013), transplanting sagebrush plants should be considered. While large-scale transplanting is not practical, it could be useful for the establishment of seed dispersal zones. Establishment of native species can be increased when plant materials are adapted to site conditions, posttreatment precipitation is adequate, seeds are buried at proper depths, and moderate to high seeding rates are used (Davies et al. 2014; Sheley and Bates 2008; Thompson et al. 2006). Accurate weather forecasting may also improve

revegetation success by timing treatments to avoid low soil water availability (Hardegree et al. 2016, 2018). Experimentation with seed coating also shows promise in improving seeding success by protecting seeds and seedlings from frost mortality, drought, and predation (Boyd and Lemos 2013; Madsen et al. 2014; Roundy and Madsen 2016).

Biological Crusts and Fire

Fire generally results in a significant and immediate decline in the cover of biological soil crusts (Miller et al. 2013, 2014b; Warren et al. 2015). It also has a significantly greater impact on soil crusts than tree cutting (Miller et al. 2013) but has not been compared to treatments with greater soil surface disturbance such as chaining. In central Utah, cover of biological crusts in juniper woodlands were often more abundant in tree and shrub interspaces than beneath the canopies (Warren et al. 2015). Following a prescribed fire, bryophyte cover in the interspace declined from 13 percent to 3 percent and lichens from 6 percent to 4 percent. Beneath tree and sagebrush canopies, bryophytes and lichens were uncommon and thus little affected by fire. However, the loss of tortula moss beneath the tree canopies was nearly complete after the fire. Tortula moss commonly occurs beneath shrub and tree canopies where fire severity is typically high (Warren et al. 2015). On two cool and moist ecological sites, prescribed fire reduced biological soil crust cover from 6 percent to 2 percent and from 3 percent to just a trace (Miller et al. 2013; O'Connor et al. 2013). In several warm and dry sites, crust cover was reduced from 28 percent to 8 percent. In the woodlands on warm and dry sites, biological soil crusts were reduced from 3 percent to trace in Phase II and 1.5 percent to trace in Phase III (Bates et al. 2014). There was little recovery of biological soil crusts 9 years after a fire on a Wyoming big sagebrush site bordering warm/cool and dry/moist conditions (Bates et al. 2014). Little work has been done comparing the impacts of mechanical treatments on biological crusts. However, we would expect the impact to vary with the amount of surface area affected and the severity of the mechanical footprint.

CONCLUSION: WHAT WE HAVE LEARNED

The pinyon and juniper symposium held in Logan, Utah, in 1975 was an attempt to summarize 30 years of information regarding the management of these semiarid woodlands since World War II. The primary goals of vegetation management were to increase forage production and improve big-game winter habitat. Restoration of watersheds also became an important goal as a result of extensive flooding around the 1900s along the lower slopes of the Wasatch Range that caused severe cutting of stream bottoms and damage to towns. This was a result of severely overgrazed uplands. The primary method of tree removal post-World War II to the early 1970s was chaining and seeding often with introduced grasses. Conclusions in this symposium were mixed, with concerns about possible woodland mismanagement (Dwyer 1975) as observations and studies of tree removal found that understory responses to tree removal were not always positive.

Forty-eight years later, our knowledge of pinyon and juniper woodlands has significantly increased, with over 2,000 papers on the subject. Most of the soils and ecological site types across the Great Basin and Colorado Plateau have been described and mapped (or are in the process of being mapped), and we have many powerful tools including various types of imagery, computer analyses, and high-tech equipment for measuring plant physiological processes, soil moisture, microclimate, and other ecological factors. We also have become aware of the differences between persistent or presettlement woodlands and those newly expanded into shrub-grassland, savanna, riparian, and aspen communities. Common methods of tree removal today include cutting, shredding, burning, or various combinations—and in some areas, chaining. Although we have a variety of tools and information available for making informed decisions, challenges in woodland management

have significantly increased over the past decades. Temperatures have been warming over the past 100 and more years, big fires have become larger and more frequent in the past 20 years, and invasive plants are an ever-increasing problem—especially the annual grasses. Our success in seeding native plants is still inconsistent and expensive. And, funding for restoration always seems to be limiting.

What is the best form of management of these woodlands—both persistent and expanding into adjacent nonwoodland communities (fig. 5-27)? Our overall goal has changed, broadening to the management and restoration of functional ecosystems that are resilient and resistant to invasive species and resource-conserving. And we do this with careful consideration of the area's ecological characteristics and history (fig. 5-2), types of vegetation management, and methods selected—including to seed or not to seed (table 5-3)—and posttreatment management. We know that as sites become warmer and drier they become more difficult to restore. We also know that plant composition prior to treatment is very important. We recognize that with growing concerns over invasive species, the use of prescribed fire must be carefully considered and generally used in ecological sites with high resilience and resistance to invasive species. In addition to ecological and management concerns, funding is always a limiting factor in what realistically can be done. Looking for creative ways to develop resources for dollars from reduction of fuels, habitation improvement, and wood products are important components to restoring functional ecosystems.

Figure 5-27—Today we have a variety of methods for tree removal including mastication (foreground), chaining and seeding (mid-picture), cutting, and burning. All methods need to be carefully considered and should fit with ecological site characteristics, including the option of doing nothing. Eastern Nevada showing a recent mastication in the foreground and a 5-year-old chained and seeded in the background. (Photo by Rick Miller, Oregon State University.)

GLOSSARY: TERMS AND DEFINITIONS

Organized by topic: Community Ecology and Soils, Ecohydrology, Fire, and Time Periods.

COMMUNITY ECOLOGY AND SOILS

Alfisols—mineral soils that have umbric or ochric epipedons, argillic horizons, and that hold water at more than -1.5 MPa tension during at least 90 days when the soil is warm enough for plants to grow outdoors. Alfisols have a mean annual soil temperature of 8 °C or a base saturation in the lower part of the argillic horizon of 35 percent or more when measured at pH 8.2.

Alluvium—material, such as sand, silt, or clay, deposited on land by water.

Alpine—treeless communities growing above timberline; tundra—treeless communities with permanently frozen subsoil and supporting low-growing vegetation such as lichens, mosses, and shrubs.

Argillic—alluvial horizon of clay accumulation.

Aridic—see soil moisture regime.

Aridisols—mineral soils that have an aridic moisture regime, and ochric epipedon, and other pedogenic horizons but no oxic horizon.

At-risk phase—a community phase that is most vulnerable to transition to an alternative state (i.e., least resilient). See definition of phase below.

Atlantic Multidecadal Oscillation (AMO)—is a climate cycle that affects the sea surface temperature (SST) of the North Atlantic Ocean based upon the average anomalies of sea surface temperatures (SST) in the North Atlantic basin.

Attribute—a characteristic or property inherent in or ascribed to something (e.g., a fire event, current vegetation, site).

Available water holding capacity—the maximum amount of water available (percent of volume) for plants that a soil can store, which varies with such soil characteristics including texture and organic matter content.

Biological soil crusts—also known as cryptogamic, cryptobiotic, microbiotic, or microphytic soil crusts; composition of soil biotic crusts is a complex of cyanobacteria, green algae, lichens, mosses, microfungi, and other bacteria. They grow in the open interspaces of shrubs and herbs and typically increase along an environmental gradient of increasing aridity.

Broadcast seeding—scattering seed on the soil surface across an area by aerial or ground application. Success often increased if followed up by ground disturbance to help cover the seed.

Cache—seed cache is storage of seed by a hoarding animal such as rodents or birds.

Climate—general prevailing weather conditions for an area or region over a long period of time. As compared to weather, which refers to current atmospheric conditions (or over specific time period of interest; example is a 10-year period following fire).

Climax—self-perpetuating community controlled by climate and site (land) that culminates succession (Clements 1936); when vegetation is in equilibrium with all environmental factors.

Crossdating—a method used to date stumps, logs, etc., by matching patterns of wide and narrow tree rings between live and dead trees.

Cabling—a vegetation management method of pulling a long piece of steel cable across the landscape to pull up woody plants.

Comstock period—the discovery of silver in the Virginia Range in the late 1850s, which started an intense mining period peaking between 1884 and 1891 throughout Nevada, Utah, and the east slopes of the Sierras in California.

Concentrated flow—runoff that accumulates or converges into well-defined channels or rills often with sufficient energy to carry or move material and erode.

Cryic—see soil temperature regime.

Current Potential—similar to the reference state in which ecological function has not changed, the site has maintained the presence of all structural and functional groups, nutrient cycling etc., but resiliency is reduced due to the introduction of nonnative annual species (even trace). Also referred to as the "desired potential community."

Degraded seral-stage—characteristics include relatively low productivity compared to their historic state; depleted perennial herbaceous layer, increased bare ground, and invasive species are a co-dominant or dominant component of the vegetation. These communities are either an at-risk phase or have shifted to an alternate state.

Disclimax—human (Eurasian) caused disturbance(s) that degrade communities (e.g., grazing, alterations to natural fire regimes, land development, recreation, and logging)

Disturbance—any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (White and Pickett 1985, p 7).

Dioecious–male and female reproductive parts are on separate plants; contrast with monecious where male and female parts are on the same plant.

Diplochory—a seed dispersal mechanism in which a plant's seed is moved sequentially by more than one dispersal mechanism or vector.

Duripan—a subsurface horizon that is cemented by alluvial (water transported) silica to the degree that fragments from the air-dry horizon do not slake (take in water or crumble) during prolonged soaking.

Ecological Province—a subdivision of a region having a distinctive combination of geographical features and ecological sites.

Ecological Site—a kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and its response to management. Synonymous with ecological type used by USDA Forest Service; and Rangeland Ecological Site. Key components of an ecological site are climate, soils, and topography.

Ecoregion—denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources; they are designed to serve as a spatial framework of the research, assessment, management, and monitoring of ecosystems and ecosystem components. Defined at various levels; level III is similar but not identical.

Endozoochorous dispersal—dispersal of seeds via ingestion by animals.

El Niño-Southern Oscillation (ENSO)—periodic fluctuation in sea surface temperatures and air pressure influencing climate; warming and high air surface pressure phase is El Niño usually reaching full strength toward the end of the year; cooling and low air surface pressure phase La Niña.

Entisols—soils that have no distinct subsurface diagnostic horizons within 1 m of the soil surface.

Expansion—establishment of trees in places that were formerly nonwoodland.

Facultative—having the capacity to regenerate with more than one strategy (e.g., seed and vegetatively) as opposed to a seed obligate (regenerating from seed only).

Frigid—see soil temperature regime.

Fruit abscission—the dropping of fruit or seed before it is developed, usually resulting from some form of stress.

Function—purpose, action, or activity for which a thing is specially fitted or used for (e.g., function of plant cover—protect soil from raindrop impacts, provide nesting or hiding habitat).

Habitat type—see plant association.

Herb—or herbaceous, refers to the nonwoody vascular plant component, which includes both perennial and annual grasses and forbs; aboveground stems usually die back at the end of the growing season.

High pressure systems—an area where atmospheric pressure is greater than that of the surrounding area, usually associated with clear skies and calm weather.

Historical range of variability—variability in disturbances, stressors, and ecosystem attributes in the centuries immediately preceding Euro-American occupation of the region or areas that are used to provide management targets and that can maintain biological diversity and ecosystem services (Jackson 2006).

Illuvial—soil layer or horizon (e.g., argillic) in which material carried from an overlying layer has been precipitated from solution or deposited from suspension. The layer of accumulation.

Inceptisols—soils that have one or more pedogenic horizons in which mineral materials other than carbonates or amorphous silica have been altered or removed but not accumulated to a significant degree. Water is available to plants more than half the year or more than 90 consecutive days during a warm season.

Infill—increasing tree density within persistent or postsettlement woodlands that were previously of lower density.

Intercanopy—the open spaces in a woodland that occur between tree canopies.

Landscape—an expanse of land characterized by such attributes as topography, geology, soils, microclimate, and the spatial arrangement of vegetation patches, which change in both time and space giving each landscape a unique pattern. Landscapes are composed of a multitude of ecosystems at varying scales that are all connected. "A landscape is a mosaic of patches of different spatial arrangement giving each landscape a unique pattern" (Urban et al. 1987). A mosaic of land forms, vegetation, and land uses; varying in extent with the organism(s) of interest, objectives, or purpose.

Larder-hoard—the result of hoarding or caching food (seed) by animals.

Latitudinal gradient—a gradient of change that occurs predominately north and south, such as the weakening of monsoonal moisture moving from south to north.

Lithic—shallow soils over a paralithic (soft bedrock) contact or duripan (subsurface horizon cemented by bedrock).

Low pressure systems—an area where the atmospheric pressure is lower than that of the area surrounding it. Lows are usually associated with high winds, warm air, and atmospheric lifting and often associated with bad weather.

Major Land Resource Areas/MLRAs—geographically associated land resource units, usually encompassing several thousand acres. They are characterized by particular patterns of soils, geology, climate, water resources, and land use. A unit may be one continuous area or several separate nearby areas.

Mesic—see soil moisture temperature regime.

Midden—old dump or waste pile from humans and animals. Archeologists use middens found in old human-inhabited caves or in ancient dwellings to determine the types of plants and animals available during the dated time period. Especially useful are packrat middens, which contain plant macrofossils collected within 150 feet of the cave. Radiocarbon dating have dated macrofossils in some of these dung piles to be well over 10,000 years old.

Mollic Epipedon—thick, dark, soft, surface layer greater than 10 inches thick; high base saturation more than 50 percent and containing at least 1 percent organic matter.

Mollisols—mineral soils that have a mollic epipedon overlying mineral material. They can have argillic, natric, albic, cambic, gypsic, calcic, or petrocalcic horizon, a histic epipedon, or a duripan.

Monoecious—see dioecous.

Mountain shrub—higher elevation sagebrush sites that often include snowberry, serviceberry, currants, bitterbrush, and other shrub species typically growing in precipitation zones more than or equal to 14 inches.

Obligate—essential or necessary.

Old growth—see persistent and presettlement woodlands; encompasses the later stages of woodland development that typically differ from earlier stages in a variety of characteristics, which may include tree size, accumulations of large dead woody material, number of canopy layers, species compositions and ecosystem function (USDA Forest Service 1993). In pinyon and juniper woodland, old-growth characteristics include the majority of the overstory tree canopy being composed of old trees (more than 250 years) and the presence of large dead wood including snags, logs, and weathered stumps (Miller et al. 2014). Characteristics of individual old-growth pinyon and juniper trees compared to younger mature trees (more than 150 years) are differences in tree canopy shape, distinct bark characteristics, and branch structure, which may include large basal branches, and dead branches often covered with lichen (fig. 25a,b). In persistent pinyon and juniper woodlands, disturbance intervals between stand-replacement events are usually measured in centuries, allowing stands to attain old-growth characteristics including trees that are many centuries old.

^{18}O—ratio of $^{18}O/^{16}O$ (ppt from the Pacific is isotopically far lighter, less ^{18}O than ppt derived from monsoon ppt; Grayson 2011, pg. 239). $^{18}O/^{16}O$ indication of water temperature. Since ^{16}O evaporates more rapidly from seawater than ^{18}O, ocean surfaces in the tropics and subtropics contain higher ratios of ^{18}O than colder Pacific waters. However, when water vapor condenses, the heavier water molecules ^{18}O tend to condense and precipitate first. Thus $^{18}O/^{16}O$ decreases farther north (greater distance from the source). Changes in climate that alter global patterns of evaporation and ppt therefore change the ratio.

Pacific Decadal Oscillation (PDO)—similar to ENSO in character but varies over 20 to 30 years, while ENSO cycles typically only last 6 to 18 months.

Paralithic—weathered layer of bedrock that becomes soft or crumbly.

Patch—a homogeneous unit of area occurring on a landscape; frequently patches are defined as distinct plant communities.

Pedogenic (fusion)—a surface layer of parent rock or sediment feeds a physicochemical and other imprints downward into a subjacent buried soil formed in a separate parent rock or sediment, leading to pedogenic fusion of the two soils.

Period—a large interval of time that has a specific characteristic and is used to categorize history, cosmology, and climate. However, in geology, period is the basic unit in which a single type of rock system is formed. Two or more periods comprise a geological Era (e.g., Quaternary = period; Quaternary + Neogene + Paleogene = Era).

Persistent pinyon-juniper woodlands—are found where site conditions (soils and climate) and disturbance regimes are inherently favorable for pinyon and/or juniper, and where trees are a major component of the vegetation unless recently disturbed by fire, clearing, or other severe disturbance. Canopy structure varies considerably, from sparse stands of scattered small trees growing on poor substrates to relatively dense stands of large trees on relatively productive sites. Either pinyon or juniper may dominate the canopy, or the two may co-dominate. The understory may be dominated by shrubs or forbs or less commonly by graminoids; a consistent feature of the understory is low total plant cover with frequent patches of bare soil or rock. Notably, these woodlands do *not* represent 20th century conversion of formerly non-woodland vegetation types to woodland but are places where trees have been an important stand component for at least the past several hundred years. Closely synonymous with potential vegetation.

Phase (community)—a plant community within a state that is hypothesized to replace other communities along traditional succession-retrogression pathways; succession from one community to the next is readily reversible over short time periods (years to decades) without management intervention because they are not separated by thresholds. However, an at-risk phase (community) may not progress directly to the most resilient community phase without passing through an intermediate phase; it may be discontinuous from the most resilient phase.

Phase I, II, III—Phase I trees are present but shrubs and herbs are the dominant vegetation influencing ecological processes on the site; Phase II trees are codominant with shrubs and herbs and all three vegetation layers influence ecological processes; Phase III trees are the dominant vegetation on the site and the primary plant layer influencing ecological processes on the site (from Miller et al. 2005). Phases can be quantified using total perennial cover of primary functional groups to calculate a total tree dominance index (TDI) (from Williams et al. 2017).

> ***Phase I***—total tree / total tree + shrub + perennial grass = less than 0.34 (tree cover less than one-third)
>
> ***Phase II***—total tree / total tree + shrub + perennial grass = 0.34–0.67 (tree cover one-third to two-thirds)
>
> ***Phase III***—total tree / total tree + shrub + perennial grass = more than 0.66 (tree cover more than two-thirds)

Pinyon and juniper savannas—typically defined as areas of sparse tree cover (less than 10 percent tree cover) and an understory of perennial grasses.

Plant association—or "habitat type"; a reoccurring plant community with a definite floristic composition, specific diagnostic species, uniform habitat conditions, and uniform physiognomy; typically designated by a diagnostic overstory and understory species (e.g., ponderosa pine/Idaho fescue, mountain big sagebrush/bluebunch wheatgrass). *"Relatively stable, fully developed (mature) communities"* (Tansley, A.G. 1920).

Plant community—a relatively homogeneous assemblage of species growing at a particular point in time and space (synonymous with phase); often defined by the dominant species. *"Uniformity, area, boundary, and duration are the essential components of a plant community"* (Gleason H.A. 1939).

Postsettlement—see presettlement.

Presettlement woodlands—woodlands and trees that occupied the landscape prior to settlement and thus in the absence of Eurasian disturbances. The decade of the 1850s is most frequently used to separate presettlement and postsettlement, although livestock were introduced into portions of the Southwest prior to 1850. These woodlands often exhibit old-growth characteristics unless recently disturbed.

PZ—precipitation zone; used by the NRCS when mapping soils and ecological sites.

Rainsplash erosion—when rain falls at sufficient intensity, individual raindrops can detach and move soil particles a short distance.

Reference state—historic or potential plant community including seral (successional) stages; based on conditions believed to be present before widespread alterations by Euro-Americans. (see current potential).

Reference site—a location (stand or watershed) that demonstrates a reference state.

Resilience—the capacity of an ecosystem to regain its fundamental structure, processes, and functioning when subjected to stressors or disturbances like drought, livestock grazing, or wildfire. In this context, resilience is a function of the underlying ecosystem attributes and processes that determine ecosystem recovery, rather than the amount or magnitude of stress or disturbance that an ecosystem can withstand before changes in attributes and processes result in new alternative states. In summary—the ability to recover.

Resistance—the capacity of an ecosystem to retain its fundamental structure, processes and functioning (or remain largely unchanged) despite stressors or disturbances.

Resistance to invasives—the abiotic and biotic attributes and ecological processes of an ecosystem that limit the population growth of an invading species.

Savanna—pinyon and juniper savannas are found where local soils, climate, and fire regime were suitable for both trees and grasses, resulting in a low tree density.

Scatter-hoard—hiding food in many different places within a territory of a scatter-hoarder, typical birds or small mammals.

Sea Surface Temperatures (SST)—surface temperatures in various geographic portions of the oceans that influence climate.

Semiarid climate—regions that receive precipitation below potential evapotranspiration but not extremely; intermediate between arid and humid often supporting shrubs and grasses as compared to arid that supports scrubby vegetation.

Seral (sere)—a plant community that occurs during ecological succession. Seral stages for a site range from early seral following a stand-preplacing disturbance to late seral, which represents a relatively stable community in the absence of a stand-replacing disturbance event.

Shallow soil—see soil depth.

Sheet erosion—detachment of soil particles by raindrop impact and their removal downslope by water flowing overland as a sheet instead of in definite channels or rills.

Shredding—another term used for mastication, a method of using heavy machinery with grinder blades that chips trees or mulches woody plants.

Skeletal soils—contain 35 percent or more (by volume) of rock fragments, cobbles, and gravel having diameters greater than 0.08 inches (2 mm) within shallow depths (less than 20 inches).

Soil depth—very shallow = less than 10 inches; shallow = 10 to 20 inches; moderately deep = 20 to 30 inches; deep = greater than 30 inches.

Soil moisture regime—considered an important soil property in combination with soil temperature that influences plant growth and biological soil processes. The regime is based on the amount of soil moisture available during the growing season in areas with moist-cool winters and hot-dry summers. Although mapped at distinct breaks in precipitation (less than 12 inches or more than 12 inches), soil moisture regimes in reality are continuous gradients changing with location and elevation. It is important to consider where the site fits in along the gradient; for example, a site with an aridic moisture regime that receives 11.5 inches of precipitation will often be more resilient to disturbance than an aridic site receiving 9 inches of precipitation. For a detailed definition and description for each soil regime, see USDA NRCS (1999).

> ***Aridic*** (dry; mapped at less than 12 inches)—dry in all parts of the profile more than half the time when soils are more than 41 °F at 20 inches. In the Great Basin and Columbia Basin, aridic soils are usually mapped in precipitation zones receiving less than 12 inches. However, soils (e.g., lithic or shallow) with limited storage capacity may be mapped as aridic even though the site may receive more than 12 inches of precipitation. Indicator plants are desert shrub, black sagebrush, and Wyoming big sagebrush.
>
> ***Xeric*** (moist; mapped at more than 12 inches)—soils are moist in some part of the profile more than 50 percent of the time that soils are more than 41 °F, or in 6 or more years out of 10 is moist in some part for at least 90 consecutive days when soil temperatures are continuously higher than 47 °F. In the Great Basin and Columbia Basin, aridic soils are usually mapped in precipitation zones receiving more than 12 inches. Indicator plants are mountain big sagebrush, low sagebrush, pinyon pine, and Utah or western juniper. Snowberry and serviceberry also often occur as moisture increases above 12 inches and/or near the boundary of frigid and cryic soils.
>
> ***Ustic*** (summer)—moisture regime is intermediate between the aridic and udic regimes (udic soils are of humid climates with well-distributed rainfall that usually is not limiting during the growing season). Its concept is one of moisture that is limited but is present at a time when conditions are suitable for plant growth (summer). The concept of the ustic moisture regime is not applied to soils that have cryic or pergelic soil temperature regimes (defined below). This moisture regime is usually associated with warm season (C4) grasses. Ustic—

moisture regime is limited but present when conditions are suitable for plant growth in the summer. Udic—moisture is not limiting for plant growth.

Soil temperature regime—considered an important property of a soil along with soil moisture that influences plant growth and biological soil processes. Usually measured at the 20 inch depth (0.5 m) (or depth at the lithic or paralithic contact), which is considered deep enough to reflect seasonal temperatures and not daily cycles. Since measurements of seasonal soil temperatures are spatially limited across the Great Basin, soil temperature regimes are estimated based on seasonal air temperatures, which are largely influenced by location, elevation, and aspect. When soils are mapped, temperature regimes are most commonly based on elevation and aspect, which are adjusted for each sub-region (MLRA). For a detailed definition and description for each soil regime, see USDA NRCS (1999).

Mesic (warm)—mean annual soil temperature is more than or equal to 47 °F but less than 59 °F and the difference between mean summer and winter soil temperature is more than 9 °F at 20 inches soil depth. Elevation break between mesic and frigid varies with MLRA; (e.g., Malheur High Plateau 4,000 feet on the flat, ± 500 feet adjustment for north or south aspect); Central Nevada Basin and Range and the Great Salt Lake Basin MLRAs mesic soils are mapped up to 5,500 and 6,500 ft. Wyoming big sagebrush, black sagebrush, and desert shrub most frequently occupy mesic soils. Mesic soils have a low relative resistance to invasive plants compared to frigid and cryic soils. They are also considered to have lower resilience.

Frigid (cool)—mean annual soil temperature is less than 47 °F and the difference between mean summer and winter soil temperature is more than 9 °F at 20 inches soil depth. Usually mapped above 4,000 feet (± 500 feet depending on south or north aspect) in the Malheur High Plateau and between 6,000–8,500 feet Central Nevada Basin and Range and the Great Salt Lake Basin MLRAs. Indicator species are mountain big sagebrush, pinyon pine and low sagebrush (shallow soil), although black sagebrush and occasionally Wyoming big sagebrush may occur on the warmer end of this soil regime or where soil moisture is limiting. Resistance to invasive species and resilience are higher than on mesic soils.

Cryic—mean annual soil temperature is more than 32 °F but less than 47 °F and is cooler in the summer than frigid soils. Usually mapped above 6,000 feet (± 500 feet depending on south or north aspect) in the Malheur High Plateau and above 8,200 feet Central Nevada Basin and Range and the Great Salt Lake Basin MLRAs. Indicator species are curlleaf mountain mahogany, white and grand fir, limber pine, lodgepole pine, and white bark pine, which typically intermingles with mountain brush, mountain big sagebrush, and low sagebrush. Resistance to invasive species is higher than mesic and frigid (although limited data to support) soils. Resilience is also high on the warm end of this regime, but declines as colder temperatures limits the length of the growing season and soil development.

Special habitats—native biological communities or ecosystems that are rare, unique, or highly productive elements of regional landscapes (Salwasser 1990).

Successional trajectories—a sequence of successional stages that can be initiated or changed by disturbance, including drought, fire, herbivory, etc.

Stand—a homogenous group of plants growing together on a contiguous area forming a subset of a plant community. Stands are the unit area measured to estimate current vegetation composition and structure for a designated plant community or ecological site.

State—a suite of plant community successional phases occurring on similar soils that interact with the environment to produce resistant functional and structural attributes with a characteristic range of variability maintained through autogenic repair mechanisms.

Subalpine woodlands—in the paleobotany literature for the Great Basin this is usually referring to woodlands composed of bristlecone, limber or white bark pine, and occasionally Engelmann spruce. (Vegetation growing on mountains just below the limit of tree growth (timberline), and above the foothill or montane zone.)

Subclimax—where natural disturbance (e.g., fire) maintains vegetation different from the climatic climax conditions.

Substrate—often refers to the upper soil horizon where plants and other organisms grow and obtain resources.

Succession—a continuous process of change in vegetation which can be separated into series or phases (Tansley 1935). A predictable, directional, and stepwise progression of plant assemblages that culminates with climax (Clements 1936).

Temporal woodland complexity—fluctuations in woodland expansion, contraction, and infill, in addition to changes in structure and composition over time.

Threshold–boundaries in space and time between alternative stable states. Thresholds are crossed when an ecosystem does not return to the original state via self-organizing processes after stress or disturbance and transitions to a new alternative state that is adjusted to the altered attributes or processes (Stringham et al. 2003; Beisner et al. 2003).

Tree dominance index (TDI)—is a quantitative measure of the relative dominance of conifers based on canopy cover to shrub and perennial grass (or herb) cover and is calculated—tree cover/[tree + shrub + tall perennial grass cover]; e.g. TDI = 0.67 occurs when tree canopy is twice that of perennial grasses and shrubs (Roundy et al. 2014a).

Triggers—biotic or abiotic variables or events, acting independently or in combination, that initiate threshold-related processes by contributing to the immediate loss of ecosystem resilience.

Tundra—treeless communities with permanently frozen subsoil and supporting low-growing vegetation such as lichens, mosses, and shrubs. Finnish word tunturia meaning treeless plain.

> ***Arctic tundra*** occurs in the northern latitudes; low shrubs, sedges, mosses, liverworts, grasses, sedges, low herbs.
>
> ***Alpine tundra*** is found at high elevations at more southerly latitudes—grasses and sedges, dwarf trees, small-leafed shrubs, health, and low herbs.

Ustic—see soil moisture regime

Vapor pressure deficit—the difference between the actual water vapor pressure and the saturation water vapor pressure at a particular temperature.

Varve—a series of layers of sediment deposited in a body of still water in one year.

Vegetation Zones—much of the paleobotany literature refers to the vegetation zones listed below, which include characteristic plant species (Thompson 1990).

Shadscale: greasewood, shadscale, budsage.

Lower sagebrush or shrubland: big sagebrush probably Wyoming big sagebrush and basin big sagebrush and in some areas possibly black sagebrush.

Woodland: PIMO, JUOC, JUOS, big sagebrush (probably a mix of ARTRt and ARTRw depending on whether in the upper or low elevation), serviceberry, curlleaf and little-leaf mountain mahogany, mormon tea (*Ephedra viridis*).

Upper sagebrush steppe or shrubland: big sagebrush (probably mountain big sagebrush, possibly mixed with low sagebrush), silvery lupine (*Lupinus argenteus*), snowberry, occasional serviceberry, green rabbitbrush, curlleaf mountain mahogany; at the northern edge of the Great Basin common and horizontal junipers also occurred.

Montane Forest: White fir, ponderosa pine, Douglas-fir, Rocky Mountain maple, common juniper, Rocky Mountain juniper, quaking aspen, sagebrush; mainly in the south and eastern region of the Great Basin, which is lacking in the central and northwestern parts of the Great Basin, where mountain shrub (upper sagebrush-steppe or shrubland) is more common.

Subalpine woodland: bristlecone pine, limber pine, whitebark pine, subalpine fir, Engelmann spruce, prostrate or common juniper often associated with sagebrush. Sagebrush species and subspecies associated with subalpine forests are mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyanna*), mountain silver sagebrush (*A. cana* subsp. *viscidula*), low sagebrush (*A. arbuscula*), sticky sagebrush (*A. rothrockii*), and snowfield sagebrush (*A. spiciformis*).

Very shallow soil—see soil depth.

Weather—see climate.

Wooded shrublands—are found where local soils and climate support a shrub or shrub-steppe community, but trees can increase during moist climatic conditions and periods without disturbance and decrease with droughts and following disturbances (Romme et al. 2009). They can also be low sagebrush communities with sparse stands of trees, where densities are limited by soil conditions.

Woodlands—typically refer to land covered by trees to low-density forest with open habitats. Pinyon and juniper are typically referred to as woodlands and in the paleo-literature stands of bristle cone, limber pine, and whitebark pine are often called woodlands.

Xeric—see soil moisture regime.

ECOHYDROLOGY

Hydraulic conductivities—the rate at which water is redistributed through the soil profile and is a function of pore space connectivity and soil wetness. Hydraulic conductivity increases with increasing soil wetness due to greater connectivity of wet pores. Infiltration rates for wet soils approximate saturated hydraulic conductivity and are generally greater for coarse-grained or well-aggregated soils. Hydraulic conductivity is typically measured for both unsaturated and saturated conditions, reflecting wet and dry conditions.

Infiltration rates—the velocity or speed at which water enters into the soil. It is usually measured to the depth of the water layer that can enter the soil in 1 hour.

MPa, h^{-1}, d^{-1}—abbreviation for the standard unit megapascal, used to describe the pressure ranges of hydraulic systems, such as water potentials, which relate to water availability in soils for plant growth.

Rills—concentrated flow paths or microchannels that form when surface roughness elements concentrate sheet-flow into narrow, deeper flow paths, which increase the velocity and erosive energy of runoff.

Rainsplash erosion—the transfer of sediment resulting from raindrop impact.

Sheet-flow—overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills.

Soil water repellency—is a naturally occurring soil condition that impedes infiltration and typically occurs beneath shrub, pinyon, and juniper canopies. Water repellent soils form by the coating of articles with hydrophobic compounds leached from organic matter accumulations, microbial byproducts, or fungal growth under litter and duff.

Soil water zone—the uppermost portion of the soil profile where soil water is obtained and used by plants or evaporated into the atmosphere.

Splash-sheet erosion—the combined effects rainsplash and sheet-flow erosion.

Vesicular crusts—fragments of physical crusts disperse or "melt" when placed in water. A vesicular crust is a type of physical crust with many small, unconnected air pockets or spaces similar to those in a sponge.

FIRE

Crown fire—fire that burns in the crowns of trees and shrubs. Usually ignited by a surface fire. Crown fires are common in coniferous forests and chaparral-type shrublands.

Duff—partially decomposed organic matter lying beneath the litter layer and above the mineral soil typically found beneath the tree and shrub canopies.

Fire duration—the length of time that combustion occurs at a given point. Fire duration relates closely to downward heating and fire effects below the fuel surface as well as heating of tree boles above the surface.

Fire frequency—the number of times that fires occur within a defined area and time period. Also expressed as the average time interval between successive fires or the number of fires within a specific period of time.

Fire intensity—a general term relating to the heat energy released in a fire; the amount and rate of surface fuel consumption.

Fire interval—or "fire free interval" or "fire return interval"; the number of years between two successive fires documented in a designated area (i.e., the length of time between two successive fire occurrences); the size of the area must be clearly specified (units = years).

Fire occurrence—or "fire incidence"; one fire event taking place within a designated area during a designated time (no units; either yes a fire occurs, or no a fire does not occur).

Fire regime—refers to the nature of fire occurring over long periods and the prominent immediate effects of fire that generally characterize an ecosystem; a generalized description of the pattern of repeated fire on a landscape.

Fire rotation—the length of time necessary for an area, equal to the entire area of interest, to burn; area of interest must be clearly defined (units—years/area).

Fire severity—the effects of fire on ecological processes, soil, flora, and fauna; degree to which a site has been altered or disrupted by fire.

Ground fire—fire that burns in the organic material below the litter layer, mostly by smoldering combustion. Fires in duff, peat, dead moss and lichens, and punky wood are typically ground fires.

High-severity fire regimes—typically infrequent fires (more than 100-year MFRI)—high intensity, stand-replacing fires. Dominant vegetation structure, composition and function are all markedly charged by the incident.

Low-severity fire regimes—typically frequent fires (1–25 year MFRI) with few overstory effects (low mortality of dominant vegetation) due to low intensity.

Mean fire return interval (MFRI)—or "mean fire free interval" or just "mean fire interval"; arithmetic average of all fire intervals determined in a designated area during a designated time period; the size of the area and the time period must be specified (units equal years).

Moderate-severity fire regimes typically infrequent fires (25–100 MFRI); partial stand-replacing fires including burned areas ranging from low to high-severity.

Surface fire—the flaming combustion and spread is mainly fueled from dead and live fuels near the surface of the ground including litter, grasses, forbs, low shrubs, and large woody material laying on the ground (logs and stumps).

Surface fuels—surface organic materials less than 3.3 ft, including surface litter not yet decayed enough to lose their identity, grasses and forbs, shrubs and tree seedlings less than 3 feet in height, and heavier branchwood, downed logs, and stumps interspersed with or partially replacing the litter.

TIME PERIODS

Bølling-Allerød—was a relatively warm and moist interstadial period that occurred during the final stages of the last glacial period. This warm period ran from c. 14,700–12,700 years before the present. It began with the end of the cold period known as the Oldest Dryas, and ended abruptly with the onset of the Younger Dryas.

Dryas—(Oldest) Younger Dryas—followed the Bølling-Allerød period, radio carbon dating about 11–10 ka (ka = 1000 years ago) (10.8–9.6 ka, American Meteorological Society); a period of cold climatic conditions and drought (matches Eddy and Bradley graph); but others have it 12,800–11,500 years before present. Region around Greenland cooled by 9°–12.6 °F.

Eon/ Era/ Period/ Epoch/Age (in geology)

> ***Eon***—a major division of geological time, subdivided into eras, usually representing billions of years.
>
> ***Era***—subdivision of Eon and subdivided into Periods.
>
> ***Period***—represents a time of specific geologic events.

Epoch—we are currently living in the Holocene Epoch of the Quaternary Period, which also includes the Pleistocene Epoch. The Quaternary Period is a subdivision of the Cenozoic Era.

Age—subdivision of Epoch.

Glacial Maximum—when the ice sheets were at their greatest extension during the last glacial period (20,000 ±2,000 years ago) and temperatures in the Intermountain Region at their coolest. Synonymous with full glaciation.

Holocene—last 10,000 years AMS.

Early Holocene—11,500–8,000; relatively cool and wet Holocene period.

Mid Holocene—8,000–5,500 (4,500); drought.

Little Ice Age—a period (A.D. 1300 to 1850) of colder climate and increased glaciation compared to the 20th and 21st centuries.

Medieval Warm Anomaly—a period of relatively warm and dry conditions between A.D. 900 and 1300.

Period—large intervals of time that have a specific characteristic and is used to categorize history, cosmology, and climate. However, in geology, period is the basic unit in which a single type of rock system is formed.

1. Two or more periods comprise a geological Era (e.g., Quaternary = period; Quaternary + Neogene + Paleogene = Cenozoic Era).
2. Holocene is an epoch in the Quaternary Period.
3. LIA = age (correct = LIA is not a period but could state during the time period of the LIA).

Wisconsin—was the last major advance of continental glaciers in North America 115,000–11,700 years before present.

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Appendix A. Common and Associated Scientific Plant Names From Text

Common Names	Scientific Names
Trees	
Alligator juniper	*Juniperus deppeana*
Aspen	*Populus tremuloides*
Bigtooth maple	*Acer grandidentatum*
Bristlecone pine	*Pinus longaeva*
Douglas-fir	*Pseudotsuga menziesii*
Eastern redcedar	*Juniperus virginiana*
Engelmann spruce	*Picea engelmannii*
Gambel oak	*Quercus gambeli*
Grand fir	*Abies grandis*
Limber pine	*Pinus flexilis*
Oneseed	*Juniperus monosperma*
Ponderosa pine	*Pinus ponderosa*
Rocky Mountain juniper	*Juniperus scopulorum*
Sierra juniper	*Juniperus grandis*
Singleleaf pinyon	*Pinus monophylla*
Subalpine fir	*Abies lasiocarpa*
Twoneedle pinyon	*Pinus edulis*
Utah juniper	*Juniperus osteosperma*
Western juniper	*Juniperus occidentalis*
White fir	*Abies concolor*
Whitebark pine	*Pinus albicaulis*
Shrubs	
Antelope bitterbrush	*Purshia tridentata*
Apache plume	*Fallugia paradoxa*
Basin big sagebrush	*Artemisia tridentata* spp. *tridentata*
Black sagebrush	*Artemisia nova*
Cliffrose	*Purshia mexicana*
Common juniper	*Juniperus communis*
Creeping juniper	*Juniperus horizontalis*
Curl-leaf mountain mahogany	*Cercocarpus ledifolius*
Desert peach	*Prunus andersonii*
Greasewood	*Sarcobatus vermiculatus*
Green rabbitbrush	*Chrysothamnus viscidiflorus*
Little rabbitbrush	*Chrysothamnus viscidiflorus* spp. *vicidiflorus* var. *stenophyllus*
Low sagebrush	*Artemisia arbuscula*
Mountain big sagebrush	*Artemisia tridentata* spp. *vaseyana*
Nuttall's saltbush	*Atriplex nuttallii*
Rubber rabbitbrush	*Ericameria nauseosa*
Salt rabbitbrush	*Ericameria nauseosa* spp. *consimilis*
Serviceberry	*Amelanchier alnifolia*
Skunkbush sumac	*Rhus trilobata*

(Continued)

Appendix A—(Continued).

Common Names	Scientific Names
Shadscale	*Atriplex confertifolia*
Snakeweed	*Gutierrezia sarothrae*
Snowberry	*Symphoricarpos* spp.
Spiny hopsage	*Grayia spinosa*
Winterfat	*Krascheninnikovia ceratoides*
Wyoming big sagebrush	*Artemisia tridentata* spp. *wyomingensis*
Grasses	
Alkali cordgrass	*Spartina gracilis*
Basin wildrye	*Leymus cinereus*
Blue grama	*Bouteloua gracilis*
Bluebunch wheatgrass	*Pseudoroegneria spicata*
Bottlebrush squirreltail	*Elymus elymoides*
Cheatgrass	*Bromus tectorum*
Columbia needlegrass	*Achnatherum nelsonii*
Idaho fescue	*Festuca idahoensis*
Crested wheatgrass	*Agropyron cristatum*
Indian ricegrass	*Achnatherum hymenoides*
Intermediate wheatgrass	*Thinopyrum intermedium*
James' galleta	*Pleuraphis jamesii*
Junegrass	*Koeleria macrantha*
Lemmon's needlgrass	*Achnatherum lemmonii*
Lettermen's needlegrass	*Achnatherum lettermanii*
Medusahead	*Taeniatherum caput-medusae*
Mountain brome	*Bromus marginatus*
Muttongrass	*Poa fendleriana*
North African grass	*Ventenata dubia*
Pine needlegrass	*Achnatherum pinetorum*
Red brome	*Bromus rubens*
Saltgrass	*Distichlis spicata*
Sandberg bluegrass	*Poa secunda*
Spike fescue	*Leucopoa kingii*
Thurber's needlegrass	*Achnatherum thurberianum*
Western needlegrass	*Achnatherum occidentale*
Birds	
American robin	*Turdus migratorius*
Bohemian waxwing	*Bombycilla garrulus*
Cedar waxwing	*Bombycilla cedrorum*
Clark's nutcracker	*Nucifraga columbiana*
Mountain bluebirds	*Sialia currucoides*
Mountain chickadees	*Poecile gambeli*
Pinyon jay	*Gymnorhinus cyanocephalus*
Red-breasted nuthatch	*Sitta canadensis*
Scrub-jays	*Aphelocoma californica* and *A. woodhouseii*
Townsend's solitaire	*Myadestes townsendi*
Western bluebirds	*Sialia mexicana*

(Continued)

Appendix A—(Continued).

Common Names	Scientific Names
Mammals	
Black bear	*Ursus americanus*
Black-tailed deer	*Odocoileus hemionus* spp.*columbianus*
California ground squirrel	*Otospermophilus beecheyi*
California kangaroo rat	*Dipodomys californicus*
Chipmunks	*Tamias* spp.
Cottontail rabbit	*Sylvilagus audubonii*
Coyote	*Canis latrans*
Deer mouse	*Peromyscus maniculatus*
Great Basin pocket mouse	*Perognathus parvus*
Jackrabbits	*Lepus* spp.
Least chipmunk	*Tamias minimus*
Mule deer	*Odocoileus hemionus*
Nuttall's cottontail	*Sylvilagus nuttallii*
Panamint kangaroo rat	*Dipodomys panamintinus*
Pinyon mouse	*Peromyscus truei*
Raccoon	*Procyonidae lotor*
Red fox	*Vulpes vulpes*
Ringtail	*Bassariscus astutus*
Virginia opossum	*Didelphis virginiana*
White-tailed antelope ground squirrel	*Ammospermophilus leucurus*
White-tailed deer	*Odocoileus virginianus*
Woodrats	*Neotoma cinerea* and *N. fuscipes*
Yellow-pine chipmunk	*Tamias amoenus*

Appendix B. Phase and Tree Dominance Index (TDI)

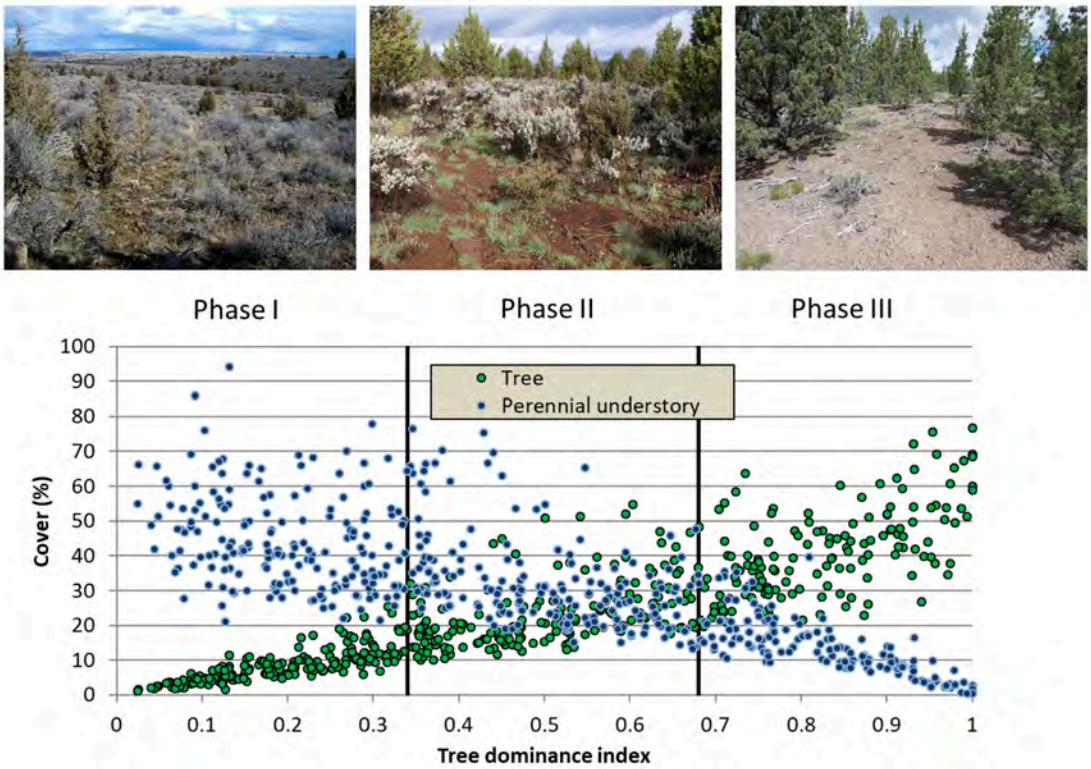
Phase I, II, III—In Phase I, trees are present but shrubs and herbs are the dominant vegetation influencing ecological processes on the site. In Phase II, trees are codominant with shrubs and herbs and all three vegetation layers influence ecological processes. In Phase III, trees are the dominant vegetation on the site and the primary plant layer influencing ecological processes on the site (from Miller et al. 2005). Phases can be quantified using perennial cover to calculate a total tree dominance index (TDI) (Williams et al. 2017).

- Phase I = total tree / total tree + shrub + perennial grass = less than 0.34 (tree cover less than one-third)
- Phase II = total tree / total tree + shrub + perennial grass = 0.34–0.67 (tree cover one-third to two-thirds)
- Phase III = total tree / total tree + shrub + perennial grass = more than 0.66 (tree cover more than two-thirds)

Tree dominance index (TDI) is a quantitative measure of the relative dominance of conifers based on the proportion of tree canopy cover to the summation of shrub and perennial grass (or herb) cover and is calculated as follows:

- Tree cover / [tree + shrub + tall perennial grass cover]

For example, TDI = 0.67 occurs when tree canopy is twice that of perennial grasses and shrubs (Roundy et al. 2014a). Tree cover can vary widely with both phase and TDI, depending on ecological site characteristics (from Williams et al. 2017).



Appendix C. State and Transition Model

Part I: State and Transition model illustrating potential changes in an old-growth twoneedle pinyon/mountain big sagebrush/bluebunch wheatgrass community following different disturbances (Stringham et al. 2015).

PIMO/JUOS/ARTRV/PSSP-ACTH7

Reference State 1.0 Community Pathways

1.1a: High-severity crown fire reduces or eliminates tree cover.

1.1b: Time and lack of disturbance such as fire, disease, or drought allows younger trees to infill.

1.2a: Time and lack of disturbance such as fire or drought. Excessive herbivory may also reduce perennial grass understory.

1.3a: Fire.

1.3b: Time and lack of disturbance such as fire or drought. Excessive herbivory may also reduce perennial grass understory.

1.4a: Low-severity fire, insect infestation, or disease removes individual trees and reduces total tree cover.

1.4b: High-severity crown fire reduces or eliminates tree cover.

Transition T1A: Introduction of nonnative annual species.

Transition T1B: Time and a lack of disturbance allows for trees to dominate site resources; may be coupled with inappropriate grazing management that favors shrub and tree dominance.

Current Potential State 1.0 Community Pathways

2.1a: High-severity crown fire reduces or eliminates tree cover.

2.1b: Time and lack of disturbance such as fire, disease, or drought allows younger trees to infill.

2.2a: Time and lack of disturbance such as fire or drought. Excessive herbivory may also reduce perennial grass understory.

2.3a: Fire.

2.3b: Time and lack of disturbance such as fire or drought. Excessive herbivory may also reduce perennial grass understory.

2.4a: Low-severity fire, insect infestation, or disease removes individual trees and reduces total tree cover.

2.4b: High-severity crown fire reduces or eliminates tree cover.

Transition T2A: Time and a lack of disturbance allows for trees to dominate site resources; may be coupled with inappropriate grazing management that favors shrub and tree dominance.

Transition T2B: Catastrophic fire.

Infilled Tree State 3.0 Community Pathways

3.1a: Time and lack of disturbance such as fire, disease, or drought allows younger trees to infill.

Transition T3A: Catastrophic fire.

Transition T3B: Loss of understory vegetation destabilizes soil surface. Inappropriate

grazing management may further reduce the perennial grass understory.

Restoration Pathway R3A: Thinning of trees coupled with seeding. Success unlikely from State 3.2.

Annual State 4.0 Community Pathways

None

Transition T4A: Catastrophic fire or multiple fires.

Eroded State 5.0 Community

Part II: State and transition model, illustrating possible woodland expansion and successional stages in a Wyoming big sagebrush/bluebunch wheatgrass with different types and severities of disturbance (Stringham et al. 2015).

Gravelly Loam 10–12 inches

Reference State 1.0 Community Phase Pathways

1.1a: Low-severity fire or aroga moth infestation creates sagebrush/grass mosaic; high-severity fire significantly reduces sagebrush cover and leads to early/mid-seral community dominated by grasses and forbs.

1.1b: Time and lack of disturbance such as fire or drought. Excessive herbivory may also decrease perennial understory.

1.2a: Time and lack of disturbance such as fire allows for regeneration of sagebrush.

1.3a: Low-severity fire or aroga moth infestation creates sagebrush/grass mosaic.

1.3b: High-severity fire or severe aroga moth infestation significantly reduces sagebrush cover leading to early/mid-seral community.

Transition T1A: Introduction of nonnative annual species.

Current Potential State 2.0 Community Phase Pathways

2.1a: Low-severity fire or aroga moth infestation creates sagebrush/grass mosaic; high-severity fire significantly reduces sagebrush cover and leads to early/mid-seral community dominated by grasses and forbs; nonnative annual species present.

2.1b: Time and lack of disturbance such as fire or drought. Inappropriate grazing management may also decrease perennial understory.

2.2a: Time and lack of disturbance such as fire allows for regeneration of sagebrush.

2.2b: Tree/shrub removal treatment or prescribed burning in the presence of annual grass species coupled with heavy spring precipitation.

2.3a: Low-severity fire or aroga moth infestation creates sagebrush/grass mosaic.

2.3b: High-severity fire or severe aroga moth infestation significantly reduces sagebrush cover leading to early mid-seral community.

Transition T2A: Time and lack of disturbance and/or inappropriate grazing management (3.1).

Transition T2B: Catastrophic fire or multiple fires (4.1), inappropriate grazing management in the presence of annual nonnative species (4.2).

Transition T2C: Time and lack of disturbance allows for trees to dominate site resources; may be coupled with inappropriate grazing management (5.1).

Shrub State 3.0 Community Phase Pathways

None.

Transition T3A: Catastrophic fire and/or soil disturbing treatments (4.1). Inappropriate

grazing management in the presence of annual nonnative species (4.2)

Transition T3B: Time and a lack of disturbance allows for trees to dominate site resources; may be coupled with inappropriate grazing management that favors shrub and tree dominance (5.1)

Restoration R3A: Shrub removal/management with minimal soil disturbance coupled with seeding of desired species (2.4).

Annual State 4.0 Community Phase Pathways

4.1a: Time and lack of disturbance (unlikely to occur).

4.2a: Fire.

Restoration R4A: Seeding of deep-rooted perennial bunchgrasses, probability of success is medium.

Tree State 5.0 Community Phase Pathways

5.1a: Time and lack of disturbance allows for tree maturation.

5.2a: Stand thinning treatment.

Restoration R5A: Tree removal with minimal soil disturbance and seeding of desired species (2.2).

Restoration R5B: Coming from Tree State 5.1 only: tree-removal treatment or controlled burn. Controlled burn only recommended if nonnative annuals are not present.

Restoration R5C: Tree removal coupled with seeding of desired species (6.2.)

Transition T5A: Catastrophic fire.

Seeded State 6.0 Community Phase Pathways

6.1a: Time and lack of disturbance may be coupled with inappropriate grazing management.

6.2a: Low-severity fire or aroga moth infestation.

6.2b: Time and lack of disturbance coupled with inappropriate grazing management reduces bunchgrasses and increases density of sagebrush; usually a slow transition.

6.3a: Fire, aroga moth infestation, or brush treatment with minimal soil disturbance.

Transition T6A: Time and lack of disturbance allows for trees to dominate site resources; may be coupled with inappropriate grazing management (5.1).

Transition T6B: Severe fire. This transition usually originates from 6.3.

MLRA 28
Group 23
PIMO/JUOS/ARTRV/PSSP-ACTH7
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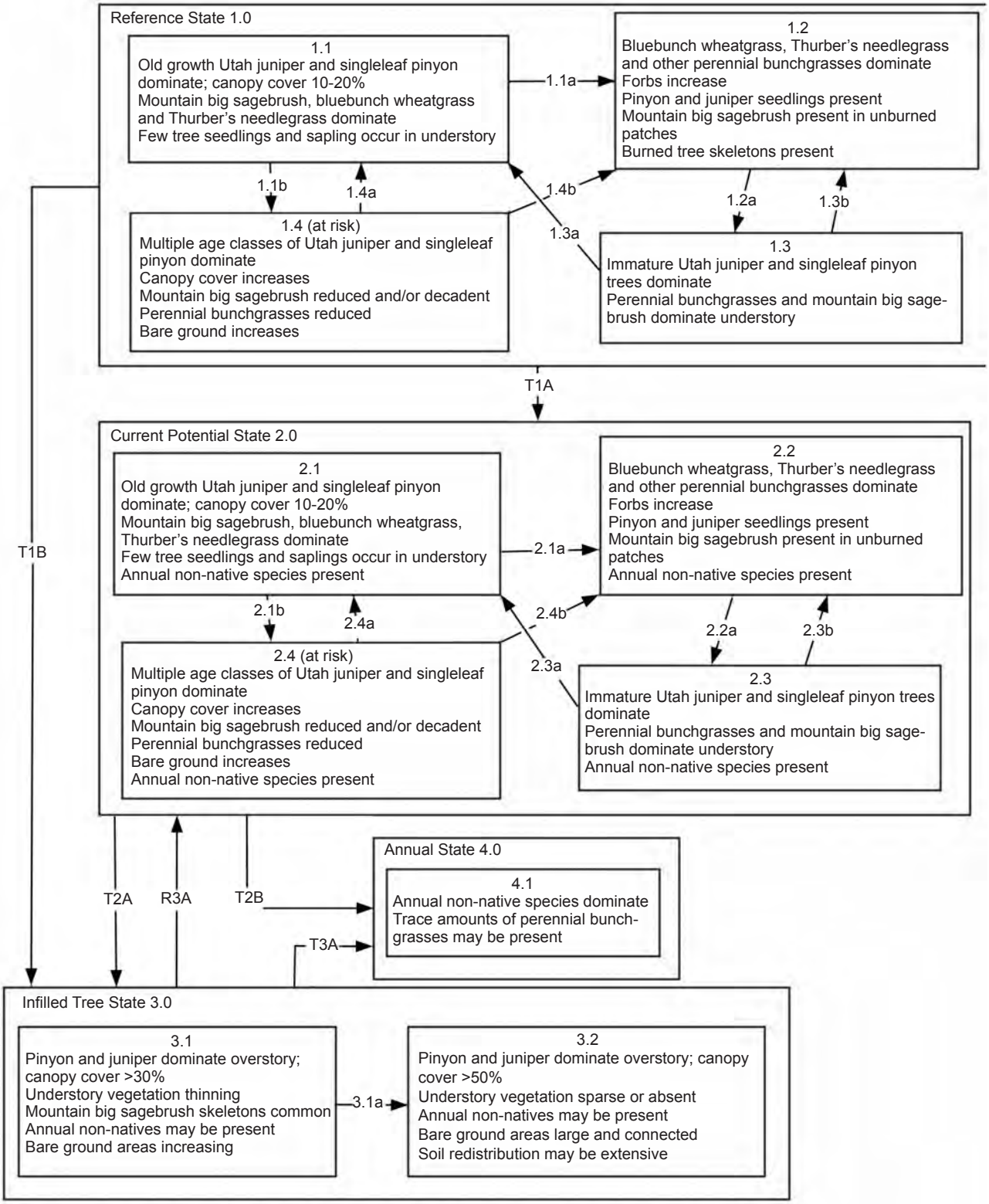

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Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions

Circular 1321

Joint Fire Science Program

U.S. Department of the Interior
U.S. Geological Survey

Sagebrush Steppe SageSTEP Treatment Evaluation Project

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Western Juniper Field Guide: Asking the Right Questions to Select Appropriate Management Actions

By R.F. Miller, Oregon State University, J.D. Bates, T.J. Svejcar, F.B. Pierson, U.S. Department of Agriculture, and L.E. Eddleman, Oregon State University

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Introduction

Strong evidence indicates that western juniper has significantly expanded its range since the late 1800s by encroaching into landscapes once dominated by shrubs and herbaceous vegetation (fig. 1). Woodland expansion affects soil resources, plant community structure and composition, water, nutrient and fire cycles, forage production, wildlife habitat, and biodiversity. Goals of juniper management include an attempt to restore ecosystem function and a more balanced plant community that includes shrubs, grasses, and forbs, and to increase ecosystem resilience to disturbances. Developing a management strategy can be a difficult task due to uncertainty about how vegetation, soils, hydrologic function, and wildlife will respond to treatments.

(*a*)

(*b*)

Figure 1. Juniper encroachment at Keystone Ranch, eastern Oregon, (*a*) about 1890 and (*b*) 1989. Photographs provided by Stu Garret.

When developing a management strategy, the first and possibly most important step towards success is asking the right questions. **Identifying the attributes** of the area to be treated and **selecting the right treatments** to be applied are of utmost importance. One must ask questions addressing the kind of site (that is, potential natural vegetation, soils, etc.), the current state of the site (that is, successional, hydrologic, etc.), what components need to be restored, how the management unit fits in with the overall landscape mosaic, and the long-term goals and objectives for the area or region. Keep in mind sagebrush-steppe vegetation is dynamic and management strategies must take into account multi-decade time frames.

This guide provides a set of tools that will help field biologists, land managers, and private landowners conduct rapid qualitative field assessments that address the kind of site and its current state. These tools include a list of questions to be addressed and a series of photographs, keys, tables, and figures to help evaluate a site. Conducting this assessment will help prioritize sites to be treated, select the best treatment, and predict outcomes.

Success of a juniper management program may be greatly enhanced if an interdisciplinary team of local managers and resource specialists, who are experienced with vegetation, fuels, soils, hydrology, wildlife, and economic and sociological aspects of the local resource, use this guide to aid their decision-making.

Supporting Literature

This guide is closely linked to the synthesis publication *Biology, Ecology, and Management of Western Juniper* by Richard Miller and others (Oregon State University Agricultural Experiment Station Technical Bulletin 152, 2005). Please refer to this publication for more information and for literature cited.

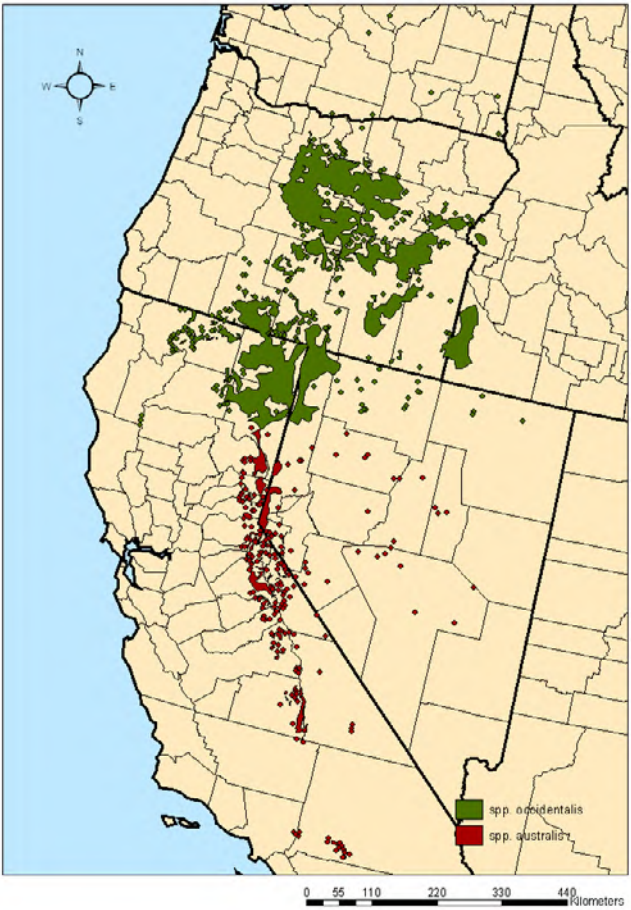

Figure 2. Current aerial distribution of western juniper (*Juniperus occidentalis*) in the western United States.

Questions to be Addressed

These questions are meant to provide a base or starting point for selecting appropriate management action. Because each management unit is unique, additional questions may need to be addressed or questions may need to be modified. The guide will focus on addressing the primary questions in Parts I, II, and III with information about the advantages and disadvantages of potential treatments in Part IV.

Setting Goals and Objectives

1. What are the desired ecological conditions or how should the site look in 5, 10, 20, or 50 years?
2. What vegetation changes need to occur to meet functional goals or habitat needs?

Answers to the questions in Parts I, II, and III will help managers determine feasible goals and objectives for a particular site. As a result, goals and objectives should be re-evaluated as these questions are answered.

Part I: Identifying the Ecological Site

3. What kind of soils are on the site?
4. How will the soils and physical features affect vegetation establishment and erosion?
5. What is the potential natural vegetation (PNV) or plant association?
6. Is there old-growth juniper on the site, and where is it growing?
7. Is the PNV woodland or shrub-steppe, and what is the fire return interval?
8. What was the past disturbance regime, and how did it influence the historic range of vegetation dynamics on the site?
9. What is the potential wildlife habitat value under PNV conditions?

Part II: Current State of the Site

10. Clearly define the perceived problems: What are the factors affecting proper ecological function?
11. Is there recruitment of native understory species?
12. What is the stage of woodland succession (Phase I, II, or III) and age structure of trees?
13. What is the understory herbaceous composition?
14. What is the percentage of dead shrubs on the site, and what are the species?
15. What are the fuel characteristics, and what type of fire will the site support (ground fire or canopy fire)?
16. Are there signs of erosion and overland flow? What is the current capacity of the site to capture, store, and safely release water?
17. What is the current wildlife habitat suitability? How will treatment affect wildlife?
18. Are there social and/or economic concerns or issues tied to the site?

Part III: Landscape Considerations

19. What are the landscape spatial characteristics of the area to be treated with respect to patch size, edge, and connectedness?
20. Are there adjacent patches and what is the landscape composition?
21. How does the site connect to the landscape?
22. What are the current uses and management activities?

Part IV: Selecting Appropriate Management Action and Treatment

23. Factors that will influence treatment selection
24. Mechanical Treatments
25. Prescribed Fire
26. Cut and Burn Combinations
27. Chemical Treatments
28. Seeding
29. How will post-treatment management affect site conditions?

Setting Goals and Objectives

1. What are the desired[1] ecological conditions or how should the site look in 5, 10, 20, or 50 years?

Desired ecological conditions depend on management objectives, potential uses for the site, and ecological characteristics of the site, such as soil profiles and ecological site type. Managers need to identify conditions that are ecologically feasible on a given landscape and that will satisfy management objectives over the long term. Then they can determine if a treatment or series of treatments could help to achieve those results.

Setting goals and objectives will often require participation by stakeholders, who may have differing or even conflicting ideas about the values that should be emphasized in juniper-dominated rangelands or the appropriate ecological condition of those lands. Natural disturbances and changes in environmental conditions also may affect the site, and management plans may need to be adjusted as a result.

Because goals and objectives are influenced by many factors, they should be reevaluated as new information becomes available and adjusted accordingly. Answers to the questions that follow in this guide will provide information to managers that will help them in the ongoing process of setting appropriate goals and objectives for a particular site.

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[1]Words such as “desired”, “desirable”, and “best” are sometimes used to describe advantageous or suitable management approaches relative to management goals and objectives and in considerations of ecological responses of vegetation, soils, hydrologic function, and wildlife. These terms are used with recognition that many factors besides the evaluations described or cited in this manual may eventually come to bear in a decision-making process. In this context, these words should be viewed as relative terms only, not as explicit directives or judgments.

2. What vegetation changes need to occur to meet functional goals or habitat needs?

After a "desired condition" has been defined (for example, fig. 3), the next step is to identify the specific vegetation changes necessary for the site to meet functional goals, such as improved watershed health or wildlife habitat. For example, an increase in shrubs and herbaceous vegetation may be needed to increase vertical diversity for wildlife. Maintaining an open woodland canopy with a diverse understory may achieve these habitat goals. An increase in shrubs also could change structural diversity to affect fuels and maintain a desired fire regime. Erosion and sedimentation may be reduced with increasing perennial grass cover, and the ability of the site to capture and store water could be improved.

Figure 3. Post-settlement Phase II western juniper stand. A management objective for this site might be to maintain a diverse understory by reducing juniper dominance.

Part I: Identifying the Ecological Site

Ecological site and soil maps for the area should be obtained and used to help determine the proper ecological site description and soils. Maps should be verified during a site visit to ensure that the given descriptions match the site.

3. What kind of soils are on the site?

A soils map of the site or area will indicate what type of soils are present.

Soil Texture (fig. 4): To determine soil texture of each horizon, add water to a healthy tablespoon of soil until you can roll it up in a ball without it leaving soil on your palm. Press the soil between your thumb and forefinger and attempt to form a ribbon.

- Good Ribbon: does not break and has few cracks = high clay content
- Medium Ribbon: ribbon cracks deeply and eventually breaks = moderate clay content
- Poor Ribbon: a ribbon cannot be formed or immediately breaks = low clay content

Add additional water and test for smoothness and grit. Gritty texture indicates sand.

Soil Depth: Soil depth is measured from the surface to the layer that retards root development:

Very shallow: <10 in.
Shallow: 10 to 20 in.
Moderately deep: 20 to 36 in.
Deep: 36 to 60 in.
Very deep: >60 in.

Restrictive soil layers increase below-ground competition. With increasing juniper dominance, herbaceous vegetation is likely to decrease on sites where there is a restrictive soil layer 16-18 in. beneath the

surface. Soil layers (for example, cemented ash, heavy clay argillic layer, etc.) that restrict water movement also will influence water runoff on the site, and this should be considered before treatment (figs. 5-7).

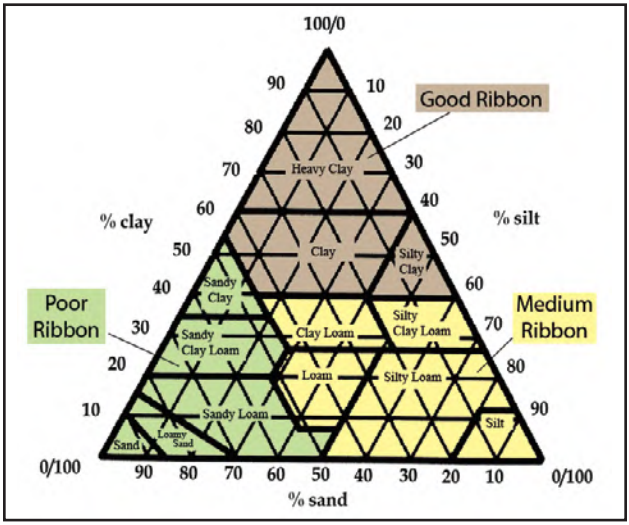


Figure 4. Soil texture triangle.

Figure 5. A cemented ash layer at 12 in., compressing the juniper roots above the restrictive soil layer.

Figure 6. Basin big sagebrush/Thurber's needlegrass plant association with a restrictive layer at 16-20 in., which limits tree rooting depth resulting in a loss of shrubs, grasses, and forbs.

Figure 7. Mountain big sagebrush/Idaho fescue plant association (Ecological site = Deep Loamy 12-16 PZ) with moderately deep (>30 in.), well-drained, clay loam soils. Western juniper roots are well distributed throughout the soil profile resulting in a loss of shrubs, but the Idaho fescue persists in the understory.

4. How will the soils and physical features affect vegetation establishment and erosion?

Soil characteristics will influence the level of risk for erosion following treatment that involves tree removal. Soil surface stability, soil texture, soil depth, aggregate stability, patterns of bare ground, and evidence of rill and sheet erosion should be examined across the site. Treatments like prescribed fire may remove a large amount of vegetation, and the site may be vulnerable to erosion in the short term. Soil can be protected by methods such as cutting juniper and leaving slash on the ground. Another factor to consider is whether past erosion due to tree dominance has changed soil characteristics in ways that will affect the success of seeding (that is, has topsoil been lost?).

Erosion Potential

Low ----------High

Infiltration Rates

High ----------Low

Soil Texture

Coarse ----------Fine

% Slope

0 ----------->30

Amount of Rock and Pebbles on the Surface

100----------0

Figure 8. A conceptual generalization of the potential for erosion and infiltration related to soil texture, slope, and the amount of gravel and pebbles on the surface.

5. What is the potential natural vegetation (PNV) or plant association?

- Which sagebrush species or subspecies is present on the site (key 1 and figs. 9-11; if Phase III, look for shrub skeletons on the site)?
- Is there evidence that pre-settlement trees occupied this site in the past (table 1 and key 2)?
- What are the diagnostic grass species?

Figure 9. Dead bitterbrush (PUTR) and big sagebrush (ARTR) remnants can be separated by differences in the wood; bitterbrush (top) is clear while sagebrush (bottom) has dark brown bands perpendicular to the annual growth rings.

Warm-Dry----------Cool-Wet
ARAR<ARTRW<ARTRT<ARTRV<ARTRV+PUTR<ARTRV+SYOR
ACTH<PSSPS<FEID<ACNE

Figure 10. Diagnostic species that indicate warm-dry to cool-wet gradient (for definitions of plant codes see appendix 2).

(*a*)

(*b*)

Figure 11. Crown of (*a*) mountain big sagebrush (ARTRV) is generally flat-topped with inflorescence >1/2 above vegetative crown, and (*b*) Wyoming big sagebrush (ARTRW) with an uneven top and inflorescence <1/2 above vegetative crown.

Key 1. Common sagebrush species associated with western juniper (figs. 10–11). Key is based on persistent leaves.

1a. Mature shrubs <18 in. tall.

2a. Flowers early summer, leaves broadly cuneate, with deep, well developed lobes, center lobe often buck-toothed (wider than space between two outer leaves), flower heads >3 mm wide.....*early sagebrush*

2b. Center lobe not buck-toothed, flower heads <3 mm wide..... *low sagebrush*

1b. Mature shrubs >18 in. tall.

3a. Plant flat-crowned, flower stalks mostly >1/2 above vegetative shoots, leaves wedge shaped and tapered to base, leaves in water fluoresce bright bluish white under ultraviolet light ..... *mountain big sagebrush*

3b. Plant crowns uneven, flower stalks throughout the crown, usually <1/2 above crown, does not fluoresce bluish under ultraviolet light.

4a. Plants usually >3 ft. tall, wedged-shaped leaves ..... *basin big sagebrush*

4b. Plants usually <3 ft. tall, bell-shaped leaves ..... *Wyoming big sagebrush*

6. Is there old-growth juniper on the site, and where is it growing?

Old-growth western juniper trees provide valuable wildlife habitat, add structural and biological diversity to the landscape, and are part of the PNV. For these reasons, it is important to identify areas where old-growth occurs and carefully consider the appropriateness and consequences of any tree removal projects that might jeopardize the integrity of these sites (that is, thinning of younger trees where there is a potential for a stand-replacement fire). Old-growth western juniper is associated with a variety of soils, landforms, and plant associations, but typically grows in rock outcrops and soils that are shallow, rocky, and often high in clay or sand content, and in fine textured sedimentary soils. Old-growth stands commonly grow in areas where fuels accumulation is limited and stand-replacement or mixed-severity fires are infrequent.

Questions to ask to determine if the site is or was an old-growth site:

- Are there trees on the site showing old-growth characteristics, or are the trees <150 years old (table 1)?
- Do the soils typically support persistent juniper woodlands, or do they have characteristics such as mollic horizons that developed under a grass or grass-shrub dominated vegetation?
- Does tree age structure suggest the site is relatively stable (limited recruitment), or are younger trees in-filling?
- Are there large stumps or snags (>18 in. but often >24 in. in diameter), often covered with char?
- Are there large logs or branches lying on the site?

Western Juniper Growth Form*		
Characteristic	**Relatively Young Trees**	**Relatively Old Trees**
Crown shape	Conical with pointed tip	Flattened, rounded, or uneven top
Branch structure	Branches become progressively smaller from bottom to top of tree	In open stands, large branches near the base
Dead wood	Little dead wood in the bole, few dead branches, little to no foliose lichen	Dead branches, bark missing, covered by a light green lichen
Bark (fig. 14)	Flaky, relatively thin with limited or shallow vertical furrows	Thick, fibrous with well-developed vertical furrows
Leader growth	Terminal leader growth in the upper 1/4 of the tree, usually >2 in. In open stands, leader growth >2 in. from bottom to top	Leader growth in the upper 1/4 of the tree usually <1 in.

*Growth form and morphological characteristics vary across trees and stands so usually several characteristics are required to separate young and old.

Table 1. Morphological characteristics of post-settlement (<150 years) and pre-settlement (>150 years) trees (figs. 12–15).

Figure 12. An 800-year-old western juniper tree with spreading rounded top and large lower limbs on sandy soils, Connely Hills, south-central Oregon. Plant association: western juniper/bluebunch wheatgrass.

Figure 13. Old-growth western juniper with considerable dead branches, missing bark and lichen, occupying a shallow heavy clay soil on the Modoc Plateau in northern California. Plant association: western juniper/low sagebrush/Sandberg bluegrass (Ecological site = Juniper Tableland 10-14 PZ).

(***a***) At 75 years, bark is thin and flaky.

(***b***) At 152 years, bark layer is thickening and beginning to develop vertical furrows.

(***c***) At 270 years, bark is thick and fibrous, with well-developed vertical furrows.

Figure 14. Bark characteristics of three western juniper trees of different ages.

Figure 15. Vigorous terminal and lateral leader growth (4-6 in.) on a sapling growing in the absence of competition from other trees.

Figure 16. Mountain big sagebrush/bluebunch wheatgrass plant association with a stand of pre-settlement trees growing on shallow soils just below the ridgetop.

7. Is the PNV woodland or shrub-steppe, and what is the fire return interval?

Key 2 can help identify the site as old-growth woodland (existing or following disturbance), tree-shrub savanna, or shrub steppe (figs. 16–17). The key also gives an estimated fire return interval (FRI) for the site. Return intervals in the key are meant only as a coarse proxy of the number of years between fires prior to Eurasian settlement if other documentation is not available.

Figure 17. Mountain big sagebrush/Idaho fescue plant association (Ecological site = Pumice 10-12PZ) in central Oregon north of Christmas Valley. Large charred stumps on shallow to moderately deep soils indicate that a low density of widely scattered trees occupied the site prior to the late 1800s. Current tree density is 30-50 times greater.

Key 2. Identifying ecological site and estimated fire return interval (FRI).

1a. Potentially can grow big sagebrush
- 2a. Old live trees on the site (>150 years old).
  - 3a. Old-growth tree canopy >20% ..... **woodland** ..... FRI >150 years
  - 3b. Old-growth tree canopy <20% ..... **tree shrub savanna**
    - 4a. Old trees on protected microsites* ..... FRI <50 years
    - 4b. Old trees scattered but on deeper soils ..... FRI 50-100 years
- 2b. No live old-growth trees on the site
  - 5a. No large dead wood or stumps on site (>12 in. diameter fluted) ..... **shrub steppe** ..... FRI <50 years
  - 5b. Large dead wood present on the site.
    - 6a. Density >22/acre ..... **woodland** ..... FRI > 150 years
    - 6b. Density <22/acre ..... **tree shrub savanna**
      - 7a. Relic wood on protected microsites ..... FRI <50 years
      - 7b. Relic wood scattered but on deeper soils ..... FRI 50-100 years

1b. Potentially can grow low sagebrush (ARAR)
- 8a. ARAR >12 in. height, FEID or PSSPS diagnostic grass (go to 2a. and 2b.)
- 8b. ARAR <12 in. height, POSA diagnostic grass
  - 9a. No live old-growth or large relic wood ..... **low shrubland** ..... FRI >150 years
  - 9b. Old live trees or large relic wood (canopy rarely exceeds 20%) ..... **tree-low shrub savanna** .... FRI >150 years

*4a. Are old trees growing uniformly or randomly across the site, or do they grow on microsites (microtopography convex, rocky, etc.)? This is more common on south slopes.

8. What was the past fire disturbance regime, and how did it influence the historic range of vegetation dynamics on the site?

The number of years between fire disturbance events (refer to key 2) will determine what kind of plant community will be most persistent on a site (fig. 18).

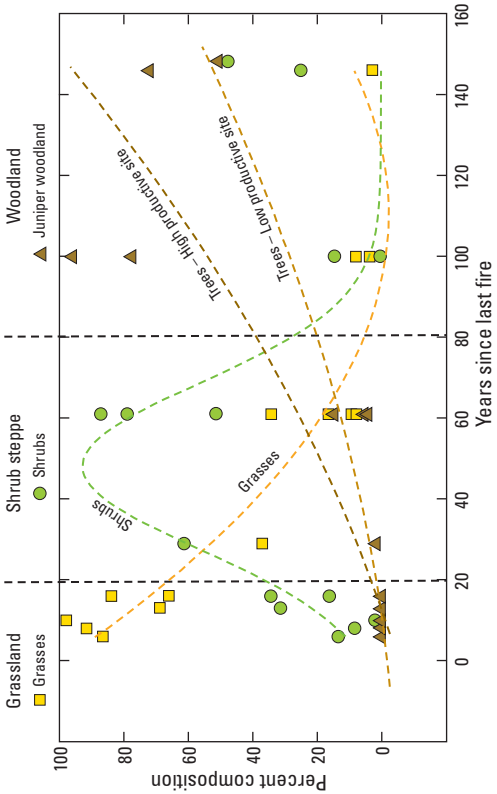


Figure 18. Relationship of time since fire and the percent composition (dominance) of grasses, shrubs, and trees.

9. What is the potential wildlife habitat value under PNV conditions?

Would vegetation on the site and surrounding area support sensitive wildlife species (that is, sagebrush obligates) (fig. 19)?

- Is it important seasonal habitat (that is, key winter, nesting, brood-rearing habitat)?
- Is it an important link between other habitats?
- What vegetation layers (herb, shrub, tree) should be present and in what relative proportion?

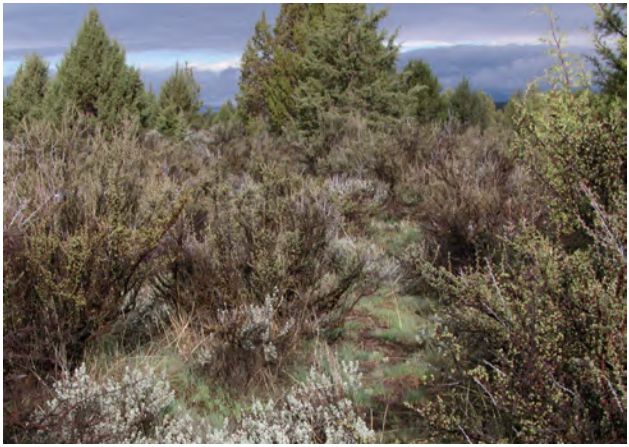


Figure 19. Phase II mountain big sagebrush-bitterbrush/Idaho fescue (Ecological site = Deep Loamy 12-16 PZ) with a high level of structural diversity. Notice the leader growth on the juniper trees in the background, which will result in rapid canopy closure, loss of shrubs, and structural diversity. Sagebrush obligates, such as the green-tailed-towhee and Brewer's sparrow, still use this site, but the sage thrasher, sage sparrow, and sage grouse are not likely to frequent such sites.

Part II: Current State of the Site

10. Clearly define the perceived problems: What are the factors affecting proper ecological function?

An important attribute that affects proper ecological function is vegetation structure, specifically the amount, type, and distribution of plant ground cover. If the site is not functional with respect to water and nutrient cycles or soil or biotic integrity, physical conditions that are connected to the problem need to be identified. Site condition should be evaluated to determine if an imbalance in plant community composition, a lack of structural diversity in the vegetation community, or a high proportion of bare ground are contributing factors. If proper ecological function or biodiversity are at risk due to encroachment or increasing density of junipers, the best way to maintain or restore hydrologic function and soil or biotic integrity is to implement treatments that reduce juniper dominance and ensure recovery or maintenance of understory vegetation on the site. Additional factors that might be weighed in treatment decisions include multiple management objectives (for example, wildlife habitat and fuels management), economic costs/benefits, and social values.

11. Is there recruitment of native understory species?

- Are there different size sagebrush or bitterbrush indicating recruitment?
- Are there perennial grass seedlings or small, young-looking bunches?

The presence of established seedlings and young plants indicates ongoing recruitment of species, while presence of healthy mature, seed-producing plants indicates that the potential for seed production still persists on the site. If old, decadent, or dying plants are common and no signs of active reproduction/recruitment are found, species are likely on the decline and the site may require restoration.

12. What is the stage of woodland succession (Phase I, II, or III) and age structure of trees?

The stage of woodland development can influence the type of treatment selected, follow-up treatments and management, understory competition, seed pools, and vegetation response following management. There are three transitional phases of juniper woodland development:

- Phase I – trees are present but shrubs and herbs are the dominant vegetation that influence ecological processes (hydrologic, nutrient, and energy cycles) on the site;
- Phase II – trees are co-dominant with shrubs and herbs, and all three vegetation layers influence ecological processes on the site;
- Phase III – trees are the dominant vegetation and the primary plant layer influencing ecological processes on the site.

Stand characteristics can be used to classify woodland development according to these phases. Early indicators to identify juniper domination of a site include shrub canopy mortality and reduction of leader growth on juniper saplings (<10 ft tall). The number of years between initial juniper encroachment and stand closure is largely determined by the rate of establishment and climate conditions (figs. 20–24 and table 2).

Phases of Juniper Woodland Succession			
Characteristics (post-settlement stands)	**Phase I (early)**	**Phase II (mid)**	**Phase III (late)**
Tree canopy (% of maximum potential)	Open, actively expanding <10%	Actively expanding 10 to 30%	Expansion nearly stabilized >30%
Leader growth (dominant trees) (cm/yr)	terminal >10 lateral >10	terminal >10 lateral 5 to >10	terminal >10 lateral <5
Crown lift* (dominant trees)	Absent	Absent	Lower limbs dying or dead where tree canopy >40%
Potential berry production	Low	Moderate to high	Low to near absent
Tree recruitment	Active	Active	Limited
Leader growth (understory trees) (cm/yr)	terminal >10 lateral >8	terminal 5 to >10 lateral 2 to >8	terminal <5 lateral <2
Shrub layer	Intact	Nearly intact to significant thinning	>75% dead

*Crown lift is the mortality of lower tree limbs, usually due to shading by neighboring trees.

Table 2. Stand characteristics differentiating three transitional phases of woodland succession for several mountain big sagebrush associations, including Thurber's needlegrass (maximum juniper cover 25-41%), Idaho fescue (maximum juniper cover 34-58%), and Columbia needlegrass (maximum juniper cover 60-75%) .

(***a***) Leader growth is between 10-15 cm (4-6 in.), Phases I and early II.

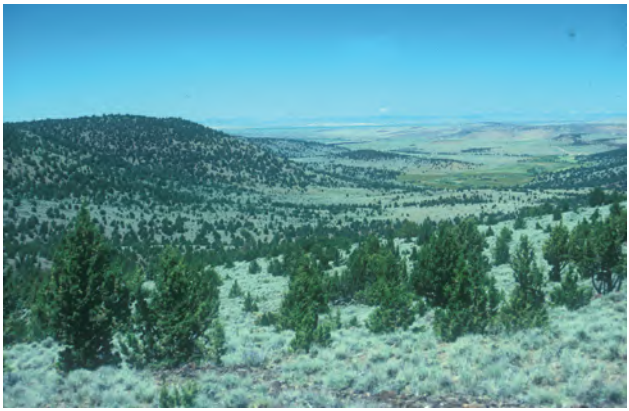
(***b***) Leader growth is 5-10 cm (2-4 in.), Phase II.

(***c***) Leader growth is <5 cm (2 in.), late Phase II and Phase III.

Figure 20. Juniper leader growth, particularly of trees <3 m tall, is a good indicator of competition stress.

Figure 21. Three phases of woodland succession in mountain big sagebrush communities.

(*a*) Subordinate - Phase I
Plant association: mountain big sagebrush/Idaho fescue
Ecological site: Deep Loamy 12-16 PZ
Maximum potential tree cover: 40-60%
Current tree cover: <5%, *shrub cover:* 40%



(*b*) Co-dominant - Phase II
Plant association: mountain big sagebrush/Thurber's needlegrass
Maximum potential tree cover: 25-35%
Current tree cover: 5-10%, *shrub cover:* 15-20%

(*c*) **Dominant - Phase III** on a north aspect and deep (for example, >61 cm or 24 in.) well-drained soil.
Plant association: mountain big sagebrush/Idaho fescue
Ecological site: Deep North 12-18 PZ
Maximum potential tree cover: 40-60%

(*d*) **Dominant - Phase III** on a south aspect with a soil restrictive layer at 41-46 cm (16-18 in.).
Plant association: mountain big sagebrush/Thurber's needlegrass
Ecological site: Juniper South 12-16 PZ
Maximum potential tree cover: 25-35%
Current tree cover: 25%, *shrub cover:* 0%

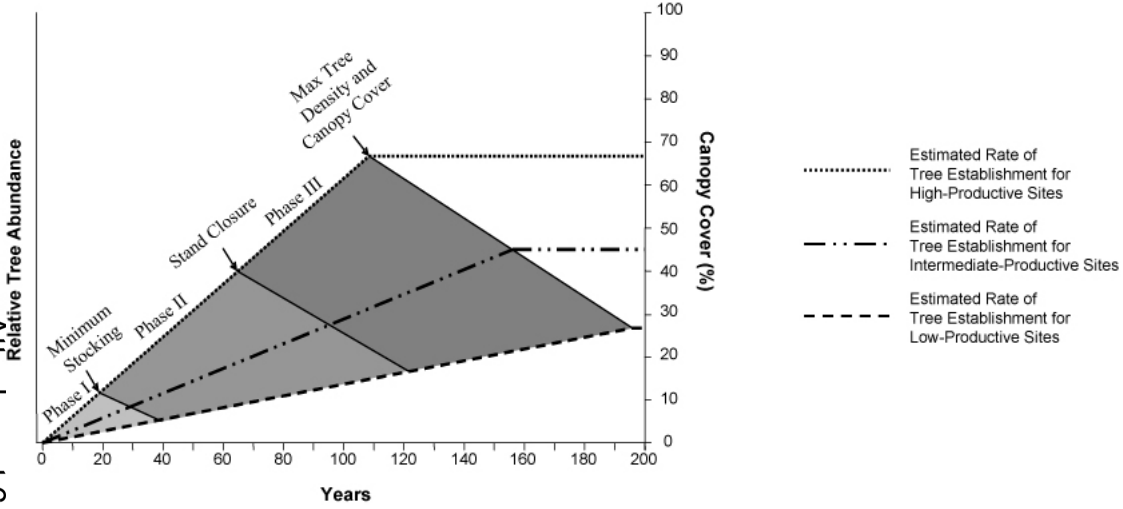


Figure 22. Conceptual model with estimated time periods from initial tree establishment (early Phase I) to minimum stocking adequate for Phase III, and estimated maximum potential for relative abundance and cover for stands developing on sites from high to low productivity (from Johnson, D.D. and R.F. Miller, 2006, Structure and development of expanding western juniper woodlands as influenced by two topographic variables. Forest Ecology and Management 229:7-15.).

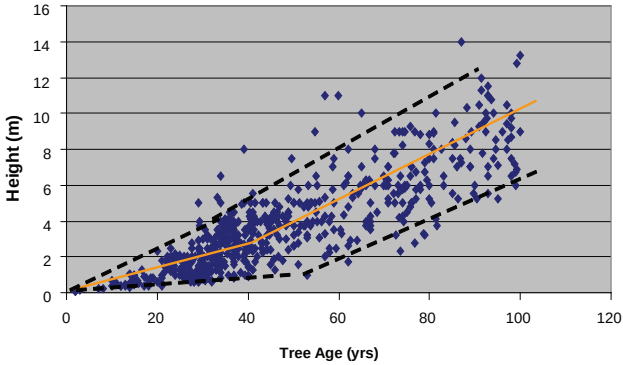


Figure 23. Relationship between age and tree height across mountain big sagebrush sites: tree height can be used as a coarse proxy to estimate stand age (multiply meters by 3.28 to convert to feet).

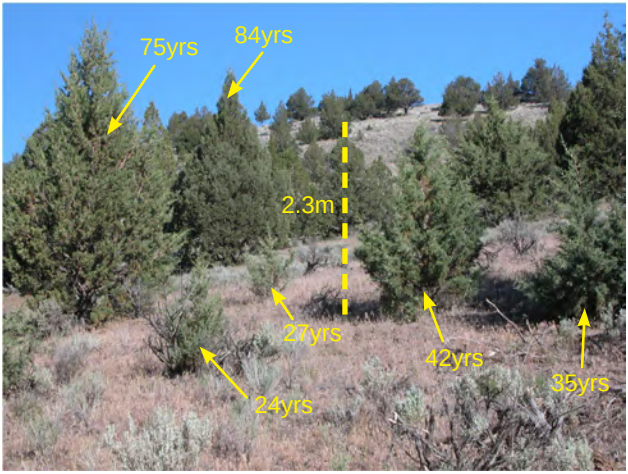


Figure 24. A mixed-age stand of post-settlement trees. For scale, the 42-year-old tree is 2.3 m (7.5 ft) tall.

13. What is the herbaceous composition?

- Is the density of tall perennial bunchgrasses adequate for restoration or should the site be seeded?
- What are the desirable species and how abundant are they?
- Is there evidence of reproductive effort for the desirable species?
- Are there young, deep-rooted perennial grasses?
- Are there threatened or endangered plant species on the site?
- Are invasive plant species present, or are seed sources near the site?

Pre-treatment understory composition has a large influence on the success or failure of efforts to restore plant communities by removing or thinning western juniper. How does current understory composition compare to the desired understory composition? Potential impacts of natural disturbance or treatment implementation on the understory should be considered. Does pre-treatment understory composition indicate that the site will recover following treatment?

Limited research suggests that if at least two deep-rooted perennial grasses (that is, Idaho fescue, bluebunch wheatgrass, needlegrass) per 1 m^2 (10 ft^2) persist on the site, recovery of understory vegetation after treatment is possible, although this is likely to vary with soil type, precipitation regime, and method of treatment (fig. 25). If perennial grasses and forbs are not present, or if the existing plants are in such poor condition that they are unlikely to survive the treatment, seeding may be necessary. The presence of an invasive species seed source, like cheatgrass, also may increase the need to quickly seed the site (fig. 26).

Invasive Plant Species

If undesirable plants, such as non-native weeds, are present on the site or present on adjacent sites, controlling their establishment and spread should be part of the management plan. Weed invasion is more likely on low-elevation and dry sites. Hot fires where woody vegetation is dense also will increase the potential of weed invasion. Several studies have shown that annual weeds can increase dramatically immediately after a tree-removal project, but often decrease over a period of years as native perennials are established on the site. A careful evaluation of expected desirable plant response based on the perennial grasses and forbs existing on the site prior to treatment, along with clear alternative plans in the event that native understory recovery does not occur as expected, will increase the likelihood of successful restoration (fig. 26).

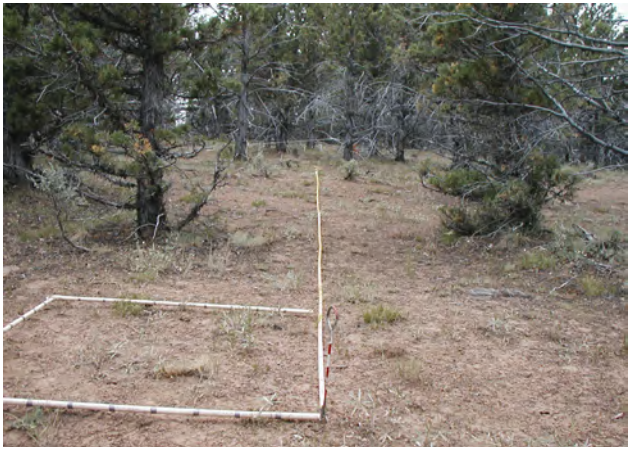


Figure 25. Phase III site with an adequate density of deep-rooted grasses (Idaho Fescue, blue bunch wheatgrass, and Thurber's needlegrass) to recover without seeding. Although fires in Phase III are infrequent, when wildfires do occur they are usually high severity resulting in greater mortality of deep-rooted perennial grasses (Ecological site = Deep Loamy 12-16PZ).

Figure 26. First growing season after a high-severity wildfire. This south aspect site burned during a hot windy August day, resulting in high mortality of an already depleted stand of deep-rooted perennial grasses and establishment of cheatgrass.

14. What is the percentage of dead shrubs on the site, and what are the species (fig. 27)?

Figure 27. Increasing juniper dominance on this site has led to increasing bare ground and mortality of understory species. Note the dead shrub skeletons. Site is in the early stages of Phase III.

15. What are the fuel characteristics, and what type of fire will the site support (ground fire or canopy fire)?

- What type of fire will the site support, and will it burn under moderate or extreme conditions (fig. 28)?

An assessment of fuel characteristics is necessary for selecting management treatments and understanding how natural processes (for example, water, nutrient, fire cycles) may be affected by treatment or no management action. Is herbaceous vegetation in the understory providing fine fuels? Does the amount of shrubs and small trees in the plant community provide sufficient ladder fuels to carry a fire into tree canopies? Does the site have a closed tree canopy that is likely to carry the fire throughout the entire site or is there an open canopy that may result in a mosaic fire pattern?

Figure 28. This site lacks both woody and herbaceous understory to carry a fire and adequate desirable herbaceous species for restoration. This Phase III woodland will burn under severe conditions and introduced annual weeds will dominate the site following fire.

16. Are there signs of erosion and overland flow? What is the current capacity of the site to capture, store, and safely release water (derived from Interpreting Indicators of Rangeland Health[2])?

- Are there rills on the site that suggest an accelerated loss of soil and water?
- What are the water flow patterns, and how do they relate to ground vegetation cover?

Sites with large amounts of bare ground, relatively fine-textured soils, steeper slopes and potential for high-intensity thundershowers are susceptible to erosion. Runoff can move continuously through connected inter-canopy zones of bare ground, and accelerated erosion is likely to be a problem on sites with these conditions. Soil in bare inter-canopy zones also is more susceptible to raindrop impact, soil crusting, decreased infiltration, and increased erosion due to lack of protection from vegetation.

A thick overstory of juniper also can reduce soil-water-capture and infiltration by limiting the amount of precipitation that reaches the ground. Research indicates that when juniper dominance is reduced, resulting in an increase in herbaceous cover on sites with relatively fine-textured soils, runoff and soil erosion decrease. Leaving juniper debris on the ground after mechanical treatments can intercept runoff and increase infiltration, as well as reduce evaporative loss of soil water. Signs of erosion may include rills, gullies, plant pedestals or terracettes, and large amounts of plant litter movement by water. Water flow patterns should be examined to determine if they indicate erosion (figs. 29-30).

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[2]Pellant, M. P. Shaver, D. Pyke and J. Herrick. 2005. Interpreting Indicators of Rangeland Health. Technical Reference 1734-6. Available online at http://fresc.usgs.gov/products/papers/1385_Pellant.pdf

Figure 29. A juniper-dominated site (Phase III) that has eroded to a restrictive layer (A horizon is gone) in the inter-canopy zone, resulting in accelerated runoff and erosion.

Figure 30. Site with large, connected zones of bare ground in the inter-canopy.

17. What is the current wildlife habitat suitability? How will treatment affect wildlife?

The habitat suitability will largely be determined by the composition and structure of vegetation at the community and landscape level. The spatial arrangement and connectedness of plant community patches are an important attribute in determining habitat suitability.

Increasing juniper dominance at the community and landscape levels results in a decline in landscape and plant community diversity, which reduces wildlife abundance and diversity. Research has not identified any wildlife species that are obligates to closed (Phase III) juniper woodlands. However, old-growth and open juniper woodlands provide important habitat. Following are some habitat suitability conditions to consider when planning treatments.

- Is the site in a transitional phase that will alter structure and composition, resulting in a change in habitat stability?
- Juniper berries (female cones) are an important winter food source for a variety of birds, so maintaining a woodland component on the site can be beneficial (fig. 31). However, berry production declines as woodlands transition toward Phase III.
- Bird species diversity and richness are greatest in Phases I and II (structural diversity of vegetation is important).
- Greater numbers of tree cavity nesting birds are usually found in old-growth juniper woodlands.
- Mule deer use juniper stands as winter cover. Dense stands with shrubs/trees more than 5 ft tall provide optimal thermal cover but minimal food resources.
- Decreases in shrubs due to woodland development results in decreased browse available for deer and other species.
- Decreases in grasses reduce seed production and seeds eaten by small mammals and birds.

Treatments such as prescribed fire may have immediate negative impacts on certain species, such as shrub-nesting birds, but may be important in limiting juniper encroachment and maintaining optimal conditions for wildlife across the landscape in the long term.

Figure 31. Mountain bluebirds consuming juniper berries early in the spring. Photograph by Rick Vetter.

Figure 32. Tree cavity in the center of the trunk of an old-growth western juniper. Old stands of trees have a relatively high density of cavity nesting birds. Photograph by Rick Vetter.

18. Are there social and/or economic concerns or issues tied to the site?

Treatment of a site may not be feasible or practical due to ecological, economic, or sociological reasons. Treatment can be expensive, especially for Phase III woodlands, because of the inputs needed to return the site to a desired condition, and achieving desired results can be difficult.

Conducting an economic evaluation may assist a manager in considering the long-term environmental consequences. Not all benefits and costs involved with these treatments are quantifiable or have dollar values attached to them. In those cases, a social benefit-cost analysis can be used to identify both the quantifiable and non-quantifiable benefits and costs. Where dollar values cannot be determined, economic principles may be applied to assist in allocating resources, such as treatment funds and labor.

Treating a stand in Phase I may make more economic sense than waiting until Phase II even though the apparent immediate benefits may be lower. Seeding can be risky on dry sites, where a high amount of erosion has occurred, where safe sites are not plentiful for seedling establishment, or where non-native invasive species are likely to quickly occupy the site. Removal of trees on sites where treatments are not likely to succeed may cause greater ecological damage (for example, increased bare ground, erosion and nutrient loss, increased weed invasion, and loss of wildlife habitat) than no management action.

Social issues to consider include wildland urban interface, values, perceived ecological impacts of different treatments, concerns for sensitive wildlife and plant species, recreation, development, archeological sites, etc.

Part III: Landscape Considerations

19. What are the landscape spatial characteristics of the area to be treated with respect to patch[3] size, edge, and connectedness?

Patch size: Treatment patch size is especially important to consider in relation to use by wildlife and livestock. Is the treatment size large enough to provide suitable conditions for wildlife species of concern? Is the treatment area so small that post-treatment overuse/overgrazing by domestic and/or wild herbivores will threaten the survival of newly established understory plants or aspen? Even with adequate forage in the area, the palatability of plants for several seasons after a fire will be higher than before, and burned patches will tend to attract wild and domestic herbivores. Is the patch size large enough to justify post-treatment management changes, such as no grazing for 1 or 2 years before or after the burn? If the treatment site is a relatively small area within a much larger pasture, resting the entire pasture from grazing may not be economically feasible or socially acceptable. Doing so may result in more ecological harm at other sites as grazing pressure is moved to those locations (on either public or private land).

Edge: Will treatment create sufficient edge habitat that is valuable to wildlife? How will the spatial distribution of edge influence seed rain from adjacent unburned sites onto the treated site?

Connectivity: Is the connectivity of various patches important for wildlife species of concern? Patch connectivity can influence wildlife movement, recruitment, predation, etc. How does distance to similar patches or patches of concern influence wildlife movement, recruitment, predation, etc.?

[3]A patch is defined here as an assemblage of plant species growing on a contiguous area forming a plant community with a defined boundary and may represent different successional states within an ecological site.

20. Are there adjacent patches and what is the landscape composition?

Considering how the site is connected to other patches and the distance to similar patches, will treatment enhance wildlife habitat and watershed health? Do corridors exist between patches for wildlife movement? Does landscape patch composition provide diverse habitat for a variety of wildlife in all seasons? How will treatment affect biodiversity at the landscape scale?

21. How does the site connect to the landscape?

Landscapes are composed of patches of different plant communities and habitats. Management of landscapes rather than individual stands includes consideration of patch composition, spatial arrangement, size, and connectivity. Consideration of which patches and how much to treat are important. Portions of these landscapes may provide key habitat for certain species (that is, sagebrush cover for sagebrush obligates or deer fawning). The initial removal of sagebrush as trees are removed may be necessary to maintain the long-term integrity of these important habitats. An alternative would be to treat a percentage of these key habitats, saving the remaining proportion for treatment at a later date when the treated areas have recovered. Maintaining a mosaic of patches of different successional stages also may be desirable for maximizing habitat diversity, reducing fuel continuity, increasing snow capture, etc.

22. What are the current uses and management activities?

It is important to consider how a treatment will affect current use and management activities in the short and long term. If the immediate treatment negatively affects wildlife habitat or livestock grazing, how long will it take to realize benefits of treatment? Are there other areas available for these uses during the short term? If the treatment location is within a larger area being managed for fuels reduction, how will treatment affect this?

Part IV: Selecting Appropriate Management Action and Treatment

Woodland structure within and across woodland successional phases will be determined by the type, frequency, and intensity of disturbance. The best management actions will be determined by the composition of all vegetation layers of the woodland, economic feasibility, and social acceptability.

23. Factors that will influence treatment selection:

- Fuel composition and structure
  - » Tree sizes
  - » Number of trees per acre
  - » Dead plant material
  - » Herbaceous plant size and density
  - » Shrub size and density
- Plant composition
  - » Abundance of desirable species
  - » Desirable fire-sensitive species (for example, sagebrush, bitterbrush)
  - » Invasive species
  - » Woodland phase
- Ecological site – risk and restoration potential
- Sensitive species (for example, sage grouse)
- Objectives
- Size of area to be treated
- Liability and proximity to other plant communities (for example, forest)
- Cost and resources
- Social acceptability

24. Mechanical Treatments

Mechanical treatments are often used to reduce juniper dominance in Phases II and III woodlands. In general, the benefits of mechanical removal of juniper include flexibility in timing of treatment application and the ability to precisely control treatment boundaries or trees targeted (for example, old-growth trees can be left as wildlife habitat). With mechanical treatments, the impact to understory vegetation is often minimal. Cut trees or slash also can be left on the site to control erosion and provide safe sites for seedling establishment, or to enhance wildlife habitat.

Disadvantages are that mechanical methods often require follow-up treatment for small trees that were not initially removed, fuel loads can be increased by leaving cut trees/slash on the site, and treatment can be difficult to implement and costly when working in areas with rough terrain. Large amounts of slash in late Phase II and Phase III create a fire hazard for a minimum of 2 years and can limit the mobility of large herbivores (domestic and wild). In addition, heavy slash, which may kill desirable plants by shading, will provide open sites for establishment of introduced species.

Patience may be required in regards to treatment response when using mechanical treatments for restoration. A delayed understory response is common. Understory response in the first year after treatment is unpredictable, and it may take several years for understory plants to fully occupy the treated area.

Heavy machinery

Heavy machinery can be used to reduce juniper dominance, but these treatments tend to be expensive. Methods include using bulldozers to push trees over, pulling anchor chains or steel cables with bulldozers to uproot trees, or use of mechanical cutting and grinding devices.

Soil conditions, such as texture and moisture content, and machinery operation (for example, use of tight turns) should be evaluated, and plans should be developed to minimize soil surface disturbance. Impacts on desirable understory vegetation also may be a concern with use of heavy machinery, but impacts have been shown to be light to moderate with chaining. Chaining has not been used in western juniper woodlands since the 1980s.

Feller bunchers, which are currently being used, cut and lay groups of 3-8 trees (depending on size) on the ground. Bundles can be left in place, burned, or chipped. However, little is known about the ecological effects of burning piles or leaving chips on site. Soil surface disturbance from feller bunchers is usually minimal on dry soils. Depending on the price being paid for chips, biomass utilization can significantly offset, if not pay for, the cost of juniper removal.

Figure 33. Juniper thinning to 5 trees/acre (12/ha) (Ecological site = Deep Loamy 12-16PZ).

Chainsaw cutting

Chainsaw cutting of juniper can be used to selectively remove trees with minimal soil disturbance. Although costs increase when treating areas with steep terrain or areas isolated from roads, cutting is an option in these areas where use of heavy machinery is not feasible. This may be the only treatment option in areas of cultural resource concern. Expense of cutting treatments increases when limbs or slash are spread across the site, so this should only be done where post-treatment erosion is a risk. This treatment will maintain and usually increase stand vigor of non-sprouting understory shrubs (that is, sagebrush).

(***a***) Before chainsaw cutting.

(***b***) One year after chainsaw cutting. All large grasses were present prior to cutting but <1 in. (2.5 cm) in diameter.

(***c***) One year after chainsaw cutting.

(***d***) Three years after chainsaw cutting; herbaceous cover 25-35%.

Figure 34. Basin big sagebrush/bluebunch wheatgrass-Thurber's plant association on a southwest aspect, 5,000 ft elevation, pre-treatment Phase III, tree canopy 25%, shrub cover 0.5%, herbaceous cover 2.5%, deep-rooted tall perennial bunchgrasses = 2/10 ft^2.

25. Prescribed Fire

The primary factors that will influence post-burn response are:

- Plant community composition
- The abundance of perennial grasses, forbs, and seed pools prior to treatment
- Ecological site (site potential)
- Fire severity
- Extent and patchiness of fire
- Pre- and post-fire climate conditions
- Post-treatment management.

Prescribed fire treatments can produce desirable results on sites with woodlands in Phases I and II when there is an abundance of natives in the understory (>2 desirable grasses/m^2). On sites that are in late Phases II and III with a depleted understory, (1) fire will be difficult to carry through the stand as a result of limited ground and ladder fuels, (2) more costly inputs are likely (see cutting and burning), and (3) response can be difficult to predict. When weeds are present on the site, risk of failure is increased, especially if the site is warm and dry, or on fine-textured soils. Additional follow-up treatments targeted at undesirable species can be beneficial.

An initial response to fire includes decreased litter and woody vegetation and increased bare ground. How will these responses affect wildlife (that is, loss of the shrub layer), water runoff, and erosion in the short term? Mountain big sagebrush usually will recover to pre-burn levels within 25–35 years (varies with climate and seed source). Controlling fire temperature and duration is important for protection of the soil and understory vegetation.

Figure 35. Phases I and II mountain big sagebrush/Idaho fescue (Ecological site = Deep North 12-18 PZ), 4,500 ft elevation, and north aspect (background); basin big sagebrush/basin wildrye (foreground) (Phase I, but little rye prior to the fire). Native perennial forbs doubled and Idaho fescue decreased about 1/3 in the first year. In year 3, perennial forbs equal to pre-burn, fescue about 120% of pre-burn. Foreground about a 600% increase in squirreltail.

Figure 36. A high-intensity wildfire was carried by the juniper canopy (35 to 40% cover) under extreme weather conditions, killing most of the understory, which included Idaho fescue, bluebunch wheatgrass, and Thurber's needlegrass. Abundant understory vegetation 2 years after fire is cheatgrass and tumble mustard. If burned under cooler conditions, the native understory would likely have survived and dominated post-fire succession (Ecological site = Juniper South 12-16 PZ).

(*a*)

(*b*)

Figure 37. Prescribed fall burns in mountain big sagebrush and Idaho fescue in (*a*) Phase II, 8-12 native grasses/m^2, and (*b*) Phase III, 4-7 plants/m^2. Mortality decreased perennial grasses to less than 2 plants/m^2 following fire in Phase III. Phase II is coming back to native grasses, while Phase III has a dominant cover of introduced annuals. Photographs by John Bates.

Burning in aspen for juniper removal

Due to high fuel-moisture conditions often found in aspen forests, prescribed fire can be difficult to implement. However, if suitable conditions exist for fire, burning can produce desirable results. Protection from livestock and wildlife use may be necessary for aspen establishment after treatment. Research indicates this could take about 3–5 years, but depends on site conditions and climate.

Figure 38. Aspen stand with dense sapling size (most of which are 40–60 years old) and western juniper in the understory. Trees will begin to dominate the stand in 20–30 years (Ecological site = Aspen Grove).

Figure 39. Aspen regeneration following a prescribed fire to remove juniper.

26. Cut and Burn Combinations

The combination of cutting and burning are used to (1) increase ground fuels to carry fire, and/or (2) remove juniper slash created by cutting. This treatment combination is most often used in late Phase II and Phase III. Fall burning in Phase III can have severe effects on understory vegetation resulting in >75% mortality. Winter burning (Nov.–Mar.) has less severe effects resulting in 20-50% mortality of perennial grasses. Cut and burn treatment of Phase III stands is higher risk and more expensive than in Phases I and II. Cutting no more juniper than is necessary is recommended to keep the treatment as cost-effective as possible and to avoid building a fuel load that will result in a fire that is too hot. Other precautions noted earlier regarding understory vegetation, erosion, wildlife habitat, economic feasibility, and social acceptability on Phase III woodlands need to be considered.

Research on social acceptability of vegetation management in rangelands has found that citizens generally prefer prescribed fire as a treatment because it is perceived as more "natural" than other treatments. However, this is true only insofar as smoke levels and risks of adjacent property damage are low; in locations near human habitation, mechanical treatment may be more acceptable to the public. All other things being equal, citizens are likely to prefer chainsaw cutting over the use of bulldozers. No research has examined the relative acceptability of cutting and grinding machines.[4]

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[4]Brunson, M.W., and B.A. Shindler, 2004, Geographic variation in social acceptability of wildland fuels management in the western U.S. Society and Natural Resources 17:661-678.

27. Chemical Treatments

Because past chemical application on western juniper has met with poor or mixed results, only limited information is available to guide managers in using this method. The most important consideration for chemical treatment of juniper woodlands is site selection. Chemical treatment should only be used on sites where the herbicide will work as intended (for example, where the soil type will not interfere with the chemical's performance) and the understory has potential to respond. Following herbicide treatment, standing dead trees may interfere with subsequent weed control and seeding of perennials. Social acceptability tends to be lower for chemical treatments than for any other restoration method.

Tebuthiuron

Aerial application of tebuthiuron is not recommended as a method for reducing western juniper dominance. Research has shown this method is not successful in killing western juniper, but can significantly reduce desirable understory plants. Applying tebuthiuron to individual trees may be an option.

Picloram

Applying picloram to individual trees around the canopy driplines can be highly effective.

Other Chemicals

Velpar L, Pronone Power Pellets, Chopper and Arsenal treatments have been shown to be effective for western juniper trees up to 6 ft in height in northern California. Chopper and Arsenal also have shown to be effective for treating cut juniper stumps with green limbs remaining below the cut.

28. Seeding

Success of seeding on sites where a treatment has been used to reduce juniper dominance is greatly influenced by precipitation and soil texture. When broadcast seeding, safe sites for seedling establishment should be created if possible. Roller punching to scarify soils, followed by broadcast seeding and scattering of slash, has been successful. Scattering slash is an expensive strategy that may only be justifiable on highly erodible soils and slopes.

Figure 40. Moderate-severity fire (notice needles on trees) where 80% of the native species in the understory survived; no seeding is required (Ecological site = Deep North 12-18PZ).

Figure 41. High-severity fire (notice no needles or bark remain on trees) where mortality of native herbaceous species was >80% ; 5 years after fire this site is dominated by introduced annual and biannual weeds; seeding required (Ecological site = Deep North 12-18PZ).

Post-Treatment Management

29. How will post-treatment management affect site conditions?

Maintenance of desirable site conditions is most likely when post-treatment management remains adaptive and flexible, and when plans are continually reassessed. An optimal management approach usually considers short- and long-term successional responses and includes evaluation of the benefits of follow-up treatments. At minimum, a good monitoring plan might include regularly taking photographs at established points and keeping a list of dominant species throughout the project area. Active monitoring can be particularly informative in areas with negative hydrologic responses or invasive species.

How will treatment influence the distribution of livestock and wildlife use of the site? Rest from grazing following treatment will significantly improve the chances of success, especially if the understory is depleted. If it is not possible to keep animals out of the treated area, grazing impacts can be reduced by controlling placement of water and mineral supplements or grazing during herbaceous dormancy in the summer and fall. After fire, 2 years of grazing rest is common practice, but plant response is often a better indicator of the actual amount of rest needed. Grazing during the growing season in the first and second years following treatment has been shown to increase mortality and decrease leaf and seed production of desirable grasses. Grazing after seed set in the first 2 years following treatment has been shown to have little effect on plant health.

It is important to provide opportunities to maximize seed production and seedling establishment. Production of grass seed is not likely to be significant until the second year post-fire. Usually, cutting and chemical applications minimally affect understory vegetation, but use of heavy equipment may have greater impact.

Appendix 1: Field Assessment Form

Site Name _____

Location _____

Date _____

I. Ecological Site / Plant Association

A. Diagnostic sagebrush species _____

_____

B. Bitterbrush present? Y / N

C. Diagnostic perennial grass(es) _____

_____

D. Old growth on the site (table 1)? Y / N

E. Large wood found on the site? Y / N

F. Plant association or PNV _____

G. Ecological Site _____

a. Soil Type _____

H. Historic Fire Return Interval (key 2) _____

I. Soil erosion potential High Moderate Low

J. Species of concern _____

II. Current State

A. Dominant shrub _____ recruitment. Y / N

B. Desirable shrub _____ recruitment. Y / N

a. % dead <10% 11-25% 26-50% >50%

C. Dominant grass(es) _____

a. ≥2 desirable grasses/m^2? Y / N

D. Post-settlement trees present? Y / N; Phase I II III

E. Invasive species present? Y / N

F. Evidence of surface erosion (rills, sediment dams, pedestals, etc.)? Y / N

G. Current plant community _____

H. Perceived problem_____

I. Habitat suitability for target species
Low Moderate High

a. If low or moderate, what is missing?_____

J. The site will burn With / Without pre-treatment.

K. Social concerns _____

L. Current uses_____

III. Landscape considerations

A. Size of area to be treated_____

B. How will treatment affect adjacent patches?_____

C. Treatment will fragment / link adjacent patches.

IV. Management Action

Phase I and/or II (circle treatment recommendation)

A. Cut

B. Burn

C. Seeding required Y / N

D. Other options_____

Phase II and/or III (circle treatment recommendation)

A. Partial cut and broadcast burn

B. Cut drop and leave

C. Cut drop and burn

D. Cut pile and burn

E. Seeding required Y / N

F. Other options_____

Considerations:

A. Small trees may require follow-up.

B. Weed potential, shrub layer, liability, structures, containment.

C. Post treatment.

D. Monitoring.

Appendix 2: Species Codes

Species Codes		
Code	**Scientific Name**	**Common Name**
AMAL	*Amelanchier alnifolia*	Serviceberry
ARAR	*Artemisia arbuscula*	Low sagebrush
ARTRW	*Artemisia tridentata ssp. womingensis*	Wyoming big sagebrush
ARTRT	*Artemisia tridentata ssp. tridentata*	Basin big sagebrush
ARTRV	*Artemisia tridentata ssp. vaseyana*	Mountain big sagebrush
PUTR	*Purshia tridentata*	Bitterbrush
SYOR	*Symphoricarpos oreophilis*	Snowberry
ACNE	*Acnatherum nelsonii*	Colombia needlegrass
ACTH	*Acnatherum thurberiana*	Thurber's needlegrass
FEID	*Festuca idahoensis*	Idaho fescue
POSA	*Poa secunda*	Sandberg bluegrass
PSSP	*Psuedorogneria spicata*	Bluebunch wheatgrass

Glossary of Terms

Bare ground: exposed mineral soil that is susceptible to raindrop splash erosion. The size, distribution, and connectedness of bare ground are the most important contributor to site stability relative to site potential.

Cover type: see potential natural vegetation.

Ecological site: a type of land with specific physical characteristics that differs from other types of land in its ability to produce distinctive kinds and amounts of vegetation and its response to management. Apparently synonymous with ecological type used by USDA Forest Service, and Rangeland Ecological Site (http://esis.sc.egov.usda.gov/Welcome/pgReportLocation.aspx?type=ESD).

Ecological function: referred to here as the actions or behavior of important processes such as hydrology, nutrient cycling, and energy capture.

Fire Return Interval (FRI) (or fire free interval or return fire interval): the number of years between two successive fires documented in a designated area (that is, the interval between two successive fire occurrences); the size of the area must be clearly specified. Variability in intervals is the meaningful reality of the disturbance regime on the site, not the mean (MFRI).

Fluted: pockets where the cambium layer folds in on itself forming deep grooves or bark pockets.

Fuel: all burnable material live and dead.

Functional goals: examples are watershed health, habitat for a defined set of species, etc., which are met by a desired set of conditions on the site often determined by vegetation composition and structure.

Gullies: channels that have been cut into the soil by moving water.

Ladder fuel: material on or near the ground that will carry fire from the ground to the crown of trees (that is, sagebrush, bitterbrush, dead down wood and branches).

Management unit: an area of land defined by boundaries where a management strategy is to be applied. The land area may be composed of one or more ecological sites, and the entire area may or may not be treated.

Mean Fire Return Interval (MFRI) (or mean fire free interval): arithmetic average of all fire intervals determined in a designated area during a designated time period; the size of the area and the time period must be specified. MFRI only provides the central tendency; variability in intervals is the meaningful reality of the disturbance regime on the site, not the mean (MFRI).

Post-settlement trees: trees establishing after 1860.

Potential natural vegetation (PNV): the vegetation that will persist under the pre-settlement disturbance regimes and climate. PNV is an expression of environmental factors such as topography, soils and climate across an area where cover type is a classification of existing vegetation. The existing cover type at any particular location and time may reflect a vegetation community anywhere along its successional pathway—from seral to climax.

Pre-settlement: trees establishing before 1860 (see old-growth).

Old-growth: a relative term that has been based on morphological characteristics, actual age, or general period of establishment (pre- and post-settlement, before or after 1860).

Rills: small erosional rivulets that are generally linear and do not necessarily follow the microtopography that flow patterns do.

Savanna or savannah: grassland or shrub-steppe with widely scattered trees (<10% canopy cover).

Soil/site stability: The capacity of an area to limit redistribution and loss of soil resources including nutrients and organic matter by wind and water (Tech. Ref. 1734-6, 2005).

Species of concern: Species that require special consideration in restoration. These include species that may increase following treatment (that is, noxious weeds) or species that are declining or appear to be in need of concentrated conservation actions, including State Endangered, State Threatened, State Sensitive, or State Candidate speices.

Stocking: A fully stocked site is one with enough trees that does or will eventually fully occupy a site (that is, at maturity, interspecific competition limits the expansion or addition of new leaf canopy). Stocking density varies across ecological sites and with tree size.

Water flow pattern: the path that water takes as it moves across the soil surface during overland flow. Evidence of water flow patterns include redistribution of litter, soil or gravel, or pedestalling of vegetation or stones.

Woodland: an area of smaller statured trees usually with canopy cover >10%; open 10-20%, intermediate 20-40%, dense >40%.

Abbreviations

Abbreviation	Definition
in.	inches
ft	feet/foot
m	meter(s)
cm	centimeter(s)
mm	millimeter(s)
ha	hectare
%	percent
yr(s).	year(s)

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To: TARDAEWETHER Kellen * ODOE
Cc: ESTERSON Sarah * ODOE; WOODS Maxwell * ODOE; Michelle Slater; David Brown; Bainter, Allison
Subject: RE: Obsidian Solar Center - Supplemental Response to DPO Comments - Attachment 3
Attachments: Attachment 3.pdf

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Hi Kellen –

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Thanks for all your work! Elaine

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Subject: RE: Obsidian Solar Center - Supplemental Response to DPO Comments - Attachment 4
Attachments: Attachment 4.pdf

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Subject: RE: Obsidian Solar Center - Supplemental Response to DPO Comments - Attachment 5
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Attachments: Attachment 6 - Part 1.pdf

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Subject: Obsidian Solar Center - Supplemental Response to DPO Comments

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Subject: RE: Obsidian Solar Center - Supplemental Response to DPO Comments - Attachment 6 (part 2)
Attachments: Attachment 6 - Part 2.pdf

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