

2011 Report Update:

**Environmental Effects of
Woody Biomass Collection and
Conversion**



November 1, 2011

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Update Report on Environmental Effects of Forest Biomass Removal

Introduction and Executive Summary

In December 2008, Oregon Department of Forestry (ODF) submitted a report entitled *Environmental Effects of Forest Biomass Removal* to the Oregon Legislature (Oregon Department of Forestry 2008). The report was completed in response to direction in Senate Bill 1072, passed by the Oregon Legislature in 2005 as part of broader efforts to reduce wildfire fuels, and to promote the health of forests and rural economies. Primarily intended to facilitate fuels reduction and ecosystem restoration projects by promoting utilization of otherwise unmerchantable woody biomass thinnings as an energy source or other forest products, SB 1072 also contained this specific direction to the State Forester:

- Prepare a report every three years¹ utilizing, to the greatest extent practicable, data collected from state and federal sources that specify the effect of woody biomass collection and conversion on the plant and wildlife resources and on the air and water quality of this state. The report shall identify any changes that the State Forester determines are necessary to encourage woody biomass collection and conversion and to avoid negative effects on the environment from woody biomass collection and conversion.

To meet its reporting requirement, the ODF has now completed this *2011 Report Update: Environmental Effects of Forest Collection and Conversion* (2011 update). In these reports, woody biomass is defined as material from trees and woody plants, including limbs, tops, needles, leaves and other woody parts that are by-products of forest management, ecosystem restoration or hazardous fuel reduction treatments.

This 2011 update complements rather than supersedes the 2008 report. The 2011 update was prepared under the assumption that readers are familiar with the 2008 report. Background and research summary information in the 2008 report is not repeated in this update. The 2011 update begins with an executive summary which includes key findings, utilization trends, and recommendations from the State Forester. The main body of the report examines what is realistic to expect from wildfire fuels treatment projects, which along with slash utilization after logging, is likely to remain an important source of forest biomass in Oregon. In the literature review, special attention is paid to studies that provide new information on additional species or resources, that address knowledge gaps or issues that have become more prominent, or that conflict in any significant way with findings described in the 2008 report. References cited along with a report methodology are also included in the appendices.

¹ The 2011 Oregon Legislature changed this reporting requirement from every three years to periodically as determined by the State Forester

Scoping for this 2011 report suggested that stakeholders and policy discussions regarding forest biomass utilization often focused on carbon and climate implications, and also on issues associated with forest soil and ecosystem productivity. In response, this update places greater emphasis on atmospheric carbon emissions and forest soil compared to the 2008 report.

Most studies reviewed for this update were suggested by staff at Oregon state resource management agencies or stakeholders in response to a solicitation made by ODF staff in spring 2011. Other studies were identified through searches and contacts made by the ODF contractor responsible for compiling the science update. Consistent with resources available to complete it, this update covers a sample of available literature and is not exhaustive. With sufficient stakeholder interest and support, the topic of environmental implications of forest biomass utilization in Oregon would be worthy of a more rigorous and thorough systematic review.

Summary of 2011 Update Findings

This 2011 update focused primarily on a sample of recent literature that addressed the effects of forest biomass removal and use on air, climate and soil resources, and also on recent research regarding effects on wildlife. In nearly all cases, research summarized in this 2011 update complements and refines research summarized in the 2008 report and does not conflict with it. One key exception is a statement that appears in the 2008 report: “Net CO₂ emissions from a biomass power plant are clearly lower than those from a fossil fuel plant...” Recent research suggests that this statement - paraphrased from a 2003 study assessing forest biomass utilization potential in three eastern Oregon counties (McNeil Technologies 2003) - is an oversimplification and thus inaccurate.

Forest biomass fuel has been considered to be “carbon neutral” because the carbon it contains was extracted from the atmosphere relatively recently as the trees and woody plants grew, and the carbon emitted when it is burned would eventually be re-extracted from the atmosphere as trees re-grew in the forest from which it was harvested (assuming no land use change in that forest). But there is an emerging debate over the “time value” of carbon, i.e. the relative values of carbon emissions and storage now and at various points in the future. In the near term, when burned in a power plant, forest biomass fuel emits more carbon per unit of energy generated than fuel oil, coal or natural gas. So a key question is, given that trees do sequester increasing amounts of carbon as they regrow, how long does it take to repay the initial “carbon debt” incurred by burning forest biomass instead of fossil fuel?

The issues of carbon budgeting and carbon neutrality of forest biomass utilization have received much attention over the past several years. These issues remain controversial, and conceptual understanding of them continues to expand and diversify. There is increasing recognition that comparisons of carbon emissions from biomass power and fossil fuel power plants can produce significantly different results depending on number of factors, including the timeframe being considered, the source of the biomass (e.g., plantations on agricultural lands;

or biomass from forests) the type of energy being produced (i.e. electrical or thermal) and the type of fossil fuel being displaced by biomass fuel.

Assessments of how biomass extraction and utilization fit into the carbon cycle are critical because they affect biomass utilization incentives and how federal agencies will account for and regulate carbon emissions from biomass energy generation and energy products. But climate implications are only one factor in the fuels reduction, ecosystem restoration and forest biomass energy equation. Fuels projects may not meet all expectations for carbon offset benefits, but they still have important, widely agreed upon roles in mitigating wildfire risk to key ecosystem values and human life and property. In cases where residual material from harvest operations, fuels reduction or ecosystem restoration projects would otherwise be open burned, dispersed forest biomass energy generation could yield carbon benefits. As researchers refine understanding of climate implications, fuels projects continue to be implemented in Oregon, producing a range of benefits to people and ecosystems, and provide an ongoing supply of forest biomass material to help meet our energy and other wood product needs.

Key findings for air resources:

1. The 2008 report oversimplified the net carbon emission implications of forest biomass energy in comparison to fossil fuel energy. Atmospheric greenhouse gas implications of burning forest biomass for energy vary in complex ways, depending on the characteristics of the bioenergy combustion or conversion technology, the fossil fuel technology it replaces, and the biophysical and forest management characteristics of the forests from which the biomass is harvested.
2. Fuels reduction, and burning forest biomass for energy may not maximize carbon storage, and ameliorate atmospheric CO₂ in as many cases as was previously assumed. Under some conditions, projects to remove forest biomass from dry eastside Oregon forests and utilize it for energy may produce net carbon benefits.
3. Studies on the effects of forest biomass energy on air resources, especially CO₂, have generated controversy over assumptions made for analysis and accounting. Accounting systems for carbon emissions associated with various forms of energy generation are still evolving. In Oregon, further study is warranted to refine understanding of inter-related carbon implications of wildfire fuel reduction, wildfire risk and severity, and utilizing residual forest biomass for energy generation or products that replace fossil fuels.

Key findings for soil resources:

1. Decomposition of down woody material improves the physical and chemical characteristics of forest soils over time by enhancing soil organic matter and nutrient content, and by increasing rates of nutrient uptake through associations with ectomycorrhizal fungi.

2. Forest biomass removal can benefit some wildlife, and improve forest health and productivity, but activities must be balanced with the need to ensure that sufficient biomass remains onsite to meet critical habitat needs, replenish soil resources and maintain ecosystem processes.
3. Increasing biomass utilization may result in greater use of whole-tree removal harvesting systems. Due to the high nutrient concentration in branches, leaves, and roots, it is essential to ensure that biomass harvesting does not deplete the long-term site nutrient capital.
4. The impact on soil nutrients from biomass removal is site dependent. Coarse-textured, low-nutrient sites are much more likely to be damaged by intensive biomass removal than sites with finer soils, higher nutrient capital or more rapid nutrient inputs.
5. Thinning operations are less likely to cause significant soil compaction, and less likely to deplete the quantity and diversity of ectomycorrhizal fungi than a stand-removal harvest.

Key findings for wildlife:

1. Identification of focal species or species of special concern in a particular fuels project area is a critical first step that can strongly influence the type and location of treatments. "Some species will gain and some species will lose habitat when stand structure or composition is changed during fuel reduction treatments." (Lemkuhl and others 2007.)
2. Thinning designed to promote species diversity will likely need locally tailored prescriptions of intensity and pattern. In general, diversity of treatments promotes diversity of species.
3. For any fuels reduction project, special attention should be given to stream-dwelling amphibians which are particularly vulnerable to changes in thermal and sediment conditions that may result from thinning in riparian areas. Adequate stream buffers are especially important for amphibians.
4. Thinning would likely benefit most species of reptiles.
5. Maintenance of adequate amounts of down woody material (DWM) for wildlife may require additional attention from managers of projects that remove material formerly regarded as waste and left in the stand.

Key findings for plant diversity:

1. The response of plant species diversity to forest thinning across most Oregon ecosystems is likely to be positive, but will depend on forest type, treatment type and treatment intensity.

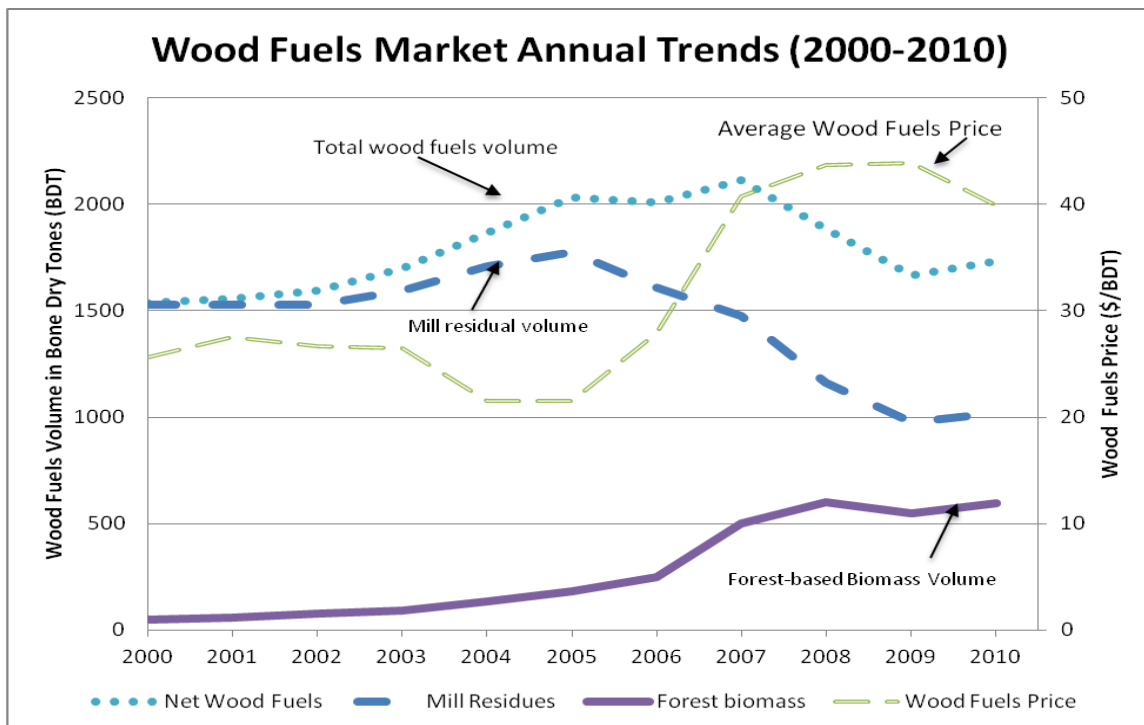
2. Depending on the site, a significant portion of increased plant species diversity resulting from thinning may be in the form of invasive exotic species. Managers should consider surveying for exotic invasives that may be present prior to thinning activities and taking steps to mitigate their spread.

Key findings for water quality:

1. The effects of various forest harvesting and thinning regimes on water quality have been extensively researched and are addressed in existing forest practice guidance for many states, including Oregon. Best forest management practices for water quality also apply to removal of forest biomass.
2. Some states are reviewing their current forest practice guidance to ensure that it fully accounts for potential differences in effects between forest biomass removal activities and conventional timber harvesting.

Woody Biomass Utilization Trends in Oregon

The graphic below shows historic information for “Oregon Wood Fuels and Biomass from 2000 - 2010”, and it is telling related to efforts to increase woody biomass utilization over the last 4 years. State incentives like the \$10 per green ton credit, and federal programs like BCAP have increased the “in-woods” biomass being delivered since 2007 to biomass plants. However, with the housing slump and the subsequent downturn in logging, overall use of woody biomass is down in this time period.



Conclusion and State Forester Recommendations (2008)

The 2008 literature review looked at resource effects of removing woody biomass as seen mainly through a sampling of fuel reduction and thinning studies. This literature suggested that care should be taken to:

- Select silviculture treatments that provide a diversity of forest structure so a wider range of habitats for wildlife and understory plants can provide for overall biodiversity.
- Leave adequate snags and downed wood during these operations to provide habitat for species that require use of them.
- Employ a skilled workforce utilizing the appropriate equipment to protect forest soils and hence the resource values dependent on them.

2011 findings build upon the 2008 findings. In addition to the above actions the 2011 findings note that:

- In Oregon, further study is warranted to refine understanding of inter-related carbon implications of wildfire fuel reduction, wildfire risk and severity, and utilizing residual forest biomass for energy.
- Coarse-textured, low-nutrient sites are much more likely to be damaged by intensive biomass removal.
- Adequate stream buffers are especially important for amphibians.
- Land managers should exercise caution to mitigate the potential for exotic invasives to spread as a result of these activities;
- Some states are reviewing their current forest practice guidance to ensure that it fully accounts for potential differences in effects between forest biomass removal activities and conventional timber harvesting.

In 2011 the State Forester continues to find that protection measures in place in Oregon across ownerships are adequate to protect forest resources during biomass removal. However, due to the gradually increasing trend of in-woods biomass utilization in Oregon the Board of Forestry has directed the Private Forest Program along with the Oregon Forest Biomass Work Group, to examine available information and evaluate the best management practices and regulations under the Oregon Forest Practices Act to proactively consider if any changes are needed to ensure continued forest resource protection as woody biomass utilization operations increase across Oregon.

Appendix A – Literature Review Update 2011

1. Introduction

The reader is reminded that this 2011 update does not provide the background on why we are examining the literature related to forest biomass utilization and its effects on forest health. Please see the original 2008 report for this background information. The intent of this 2011 update to the original report is to add to the original report new research that examines the effects of biomass utilization.

As with the first report when interpreting the information presented, care should be taken to note- where the information is available- the particular forest type being discussed, the ecological context and stand conditions prior to treatment, the silvicultural treatment that was applied and methods used to assess environmental outcomes. To some degree, findings can be extrapolated to similar forest types elsewhere in the region, but it is important to remember that pre-existing stand conditions, silvicultural treatments, study designs and analyses are rarely the same across different information sources and locales.

2. Fuels reduction projects as a source for forest biomass

As described in the 2008 report (Environmental Effects of Forest Biomass Removal, Oregon Department of Forestry 2008) projects to thin out overstocked stands and reduce the risk of uncharacteristically severe wildfire are a primary source of forest biomass in Oregon. Senate Bill 1072 was motivated, in part, by recognition that while there is general consensus on the need to reduce wildfire fuels in dry interior Oregon forests, especially in Wildland-Urban Interface (WUI) areas, the cost of such projects limits the extent to which they can be implemented. Among other goals, Senate Bill 1072 sought to increase the use of forest biomass as an energy source in order to generate additional market demand for the otherwise unmerchantable material produced by thinning densely stocked stands. State legislative incentives passed in the 2007 and 2009 sessions have increased the amount of in-woods forest biomass being utilized in Oregon.

Oregon is not alone in seeking ways to implement fuels projects and utilize material produced by them. There is strong interest in fuel reduction and use of forest biomass across the interior west, and other western states are facing similar challenges and questions regarding how best to proceed. The extent of the need for fuels reduction continues to be the subject of debate, rooted at least partially in misunderstanding about its purposes and goals. As Reinhardt and others (2008) point out, many natural resource agencies and organizations recognize the importance of treating fuels to reduce fire hazards and restore ecosystems but there continues to be confusion and misconception about fuel treatments and their implementation and effects in fire-prone landscapes. The authors explain that not all expectations for fuels projects are going to be met, but their conclusions suggest that Oregon is likely to have a continued interest in forest biomass utilization. There are significant benefits to strategically targeted fuels

reduction projects in Oregon (especially in the context of predicted climate changes) and these projects could produce considerable amounts of woody biomass.

In response to widely-held misconceptions about fuel reduction, Reinhardt and others (2008) 1) summarize objectives, methods, and expected outcomes of fuel treatments in forests of the Interior West, 2) highlight common misunderstandings and areas of disagreement, and 3) synthesize current knowledge to establish common ground for future discussion and planning. The authors' basic premise is that the primary objective for treating fuels is to make wildfire less severe (and thus more acceptable) rather than to reduce the extent of wildfires or make them easier to suppress.

In general, fuel treatments are designed to alter fuel conditions so that wildfire is less destructive. However, implicitly and explicitly, managers, the public, special interest groups and policy makers often assume different specific objectives for fuel treatments. These differences in expectation can lead to disagreement over what could be a consensus issue. Thus, Reinhardt and others (2008) lay out several common misconceptions about fuel treatments and attempt to clarify them.

First, say the authors, wildlands cannot be "fire-proofed". Fire cannot be permanently excluded from forests, especially interior forests which experience dry lightning. Even areas with intensive fuel treatments have residual biomass that, living or dead, can burn if it is dry enough. Seasonally dry and hot weather will inevitably remove sufficient moisture to allow fuels to burn if ignited.

Second, fuel treatments in wildlands should focus on creating conditions where fire can occur without devastating consequences rather than on making it easier to suppress. This may be counter-intuitive, but as Reinhardt and others (2008) explain, if fuel treatment makes suppression more successful overall, then less area will be burned in the short run and more acreage will tend to burn under extreme conditions, when suppression is ineffective. The inevitable result is that more area is burned in fewer, more unmanageable events with greater consequences. In addition, fire suppression leads to continued fuel accumulation and, in turn, more difficult conditions for suppression.

Third, even extensive fuel treatments may not reduce the amount of area burned over the long-term. In fact, reduction of area burned may actually be undesirable, say Reinhardt and others (2008). They note that there is often an implicit assumption that treating fuels will reduce future fire occurrence. But most of the acreage burned by wildfire in the US burns in a very few wildfires under extreme conditions, when suppression efforts are largely ineffective regardless of fuel conditions. Research has shown that weather (fuel moisture and wind) is far more important than fuels in determining the extent of wildfires. Research and experience suggest that reductions in fire area in the short-term resulting from suppression and fire exclusion will eventually be balanced by large burned areas over the long-term. Thus, fuel treatments designed to reduce fire area may actually cause adverse effects over time. A better approach,

say Reinhardt and others (2008), may be to target fuel treatments on reducing fire severity to save ecosystem elements that have survived numerous historical fires.

Fourth, fuel treatments should not be driven by a primary objective of reducing fire's rate-of-spread - a common metric of evaluating effectiveness of fuel treatments that is related to suppression. But as Reinhardt and others (2008) point out, after a fire is over what matters (rather than its rate of spread) are the residual onsite impacts, remaining vegetation, and the fuel complex which determine future risks and benefits. Moreover, some ecologically appropriate treatments can actually increase rate of spread, such as thinning to reduce crown fire potential. This type of thinning can result in surface litter becoming drier and more exposed to wind, and increased growth of grasses and understory shrubs which can foster rapidly spreading surface fires. For these reasons, say Reinhardt and others (2008), the fundamental goal of fuel treatment should not be to reduce spread rate but to reduce burn severity.

Fifth, treating fuels may not reduce suppression expenditures. While it is natural to assume that a fuel treatment will result in reduced suppression expenditures, say Reinhardt and others (2008), suppression costs rarely depend directly on fuel conditions, but rather on fire location and on what resources are allocated to suppression. The authors maintain that the only certain way to reduce suppression expenditures is to spend less money suppressing fires. Already, 1% of fires account for 85% of fire suppression expenditures (Brookings Institution, 2005). Since the location of these large, expensive fires cannot be predicted, fuel treatment coverage would need to be extremely extensive to prevent them. Reinhardt and others (2008) argue that many years of investment in fuel treatments, along with integrated policies that address fuel treatment and a commitment to controlling residential development of fire-prone areas and a reduction of all-out suppression efforts, is needed to effectively reduce suppression costs.

Reinhardt and others (2008) also argue that ecosystem restoration and fuel treatment are not necessarily the same. Some ecosystem restoration treatments reduce fuel hazard, but not all fuel treatments (primarily aimed at reducing fire severity) restore ecosystems. The authors maintain that it is possible to achieve both ecological restoration and fire hazard reduction, but restoration will also include reintroducing fire and other active management. For instance, thinning out small, dense trees from under a canopy of large ponderosa pine is often the first step in both ecological restoration and fire hazard reduction. Fuel treatments can also differ from ecological restoration treatments in their spatial implementation. Landscapes managed to optimize fire suppression opportunities may not emulate any historical landscape pattern and therefore may not be ecologically viable. Historical landscape mosaics were also constantly changing. Fire itself can best establish dynamic landscape mosaics that maintain ecological integrity.

Further, say Reinhardt and others (2008), while pre-European settlement conditions can provide guidance for establishing restoration goals, they probably cannot be replicated today. They state that pre-European settlement conditions are gone for good from American forests, due to residential development and invasive species, along with changed patterns and levels of

human land use. Since historical conditions varied in time and space, selecting a single target stand structure is somewhat arbitrary. Given the wide range of ecosystem conditions that may have occurred in the past, Reinhardt and others (2008) suggest a goal of restoring stand structure to within the range and variation of historical conditions on the entire landscape. The authors also make the important point that using historical conditions as the sole reference for future management is also oversimplified in an era of global change. Many outside factors now influence the structure and composition of landscapes, such as climate change, exotic weed invasions, introduced diseases, grazing by non-native herbivores and selective harvesting.

Reinhardt and others (2008) conclude by discussing the role of fuels reduction in the face of climate change. They argue that climate change makes increased resilience of forest stands an even more important goal. The effect of climate change on fire regimes remains somewhat uncertain. But there is considerable evidence that climates will become warmer and drier over the next century and that consequences of this change will be to increase (1) length of fire season, (2) severity and frequency of drought, (3) lightning ignitions, (4) amount of fuel, and (5) fuel contagion (Flannigan and Van Wagner 1991; Wotton and Flannigan 1993; Weber and Flannigan 1997; Flannigan and others 2005). As a result, ecosystems, especially those in the western US, may experience more frequent, more severe and larger fires than in the recent past. Especially disconcerting, say Reinhardt and others (2008), is that these changes in fire regime may be quite abrupt rather than gradual and will occur in ecosystems where fire has been excluded for several decades. This means that fuel treatment analyses should not be driven by specific assumptions about weather patterns and climate. The expected severity of burns coupled with extensive land area burned may have dire consequences for western US flora not adapted to this rapid change.

One way to mitigate adverse fire severity, say Reinhardt and others (2008), is to implement fuel treatments across landscapes so that when wildfires occur they will tend to be less severe. This is especially true in short fire return interval forests that historically burned in low-severity fires [such as those found in large areas of central and eastern Oregon.] Reinhardt and others (2008) summarize debate on whether fuel treatments are needed in wildland areas if climate, and therefore fire regimes, change. Some argue that climate is inherently variable and dynamic and because of this, fire regimes will change and therefore render any fuel treatment ineffective; it may be difficult to craft restoration treatments when the fire regime, and therefore desired stand conditions, are a moving target. However, say Reinhardt and others (2008), fuel treatments may be increasingly important in efforts to protect people and property from fire in the WUI and urban areas as fire seasons lengthen and become drier. Wildland ecosystems also require treatment to buffer the effects of the rapidly changing environment.

Reinhardt and others (2008) then make the case that fuels treatments may be even more important in the future. If fires tend to be larger and more severe, they say, active fuel management will be needed to minimize adverse effects of high severities and ensure post-fire landscapes contain ecologically viable patterns and composition. The best way to buffer forest ecosystems against future climate impacts is to increase their resilience. Fire was a major process on the historical landscape. Reinhardt and others (2008) argue that in anticipation of

more extensive and uncontrollable fires in the future, we must prepare the landscape to accept these changes with minor biological effects. After several decades of fire exclusion, predicted climate change may foster future wildfires in dry western forests that severely alter landscapes in structure, composition, and function. Ecosystem restoration treatments that reduce fuels may protect elements of these ecosystems as the climate changes.

3. Effects of woody biomass collection and conversion on air resources

Key findings for air resources:

- a. The 2008 report oversimplified the net carbon emission implications of forest biomass energy in comparison to fossil fuel energy. Atmospheric greenhouse gas implications of burning forest biomass for energy vary in complex ways, depending on the characteristics of the bioenergy combustion or conversion technology, the fossil fuel technology it replaces, and the biophysical and forest management characteristics of the forests from which the biomass is harvested.
- b. Fuels reduction, and burning forest biomass for energy may not maximize carbon storage, and ameliorate atmospheric CO₂ in as many cases as was previously assumed. Under some conditions, projects to remove forest biomass and utilize it for energy in dry eastside Oregon forests may produce net carbon benefits.
- c. Studies on the effects of forest biomass energy on air resources, especially CO₂, have generated controversy over assumptions made for analysis and accounting. Accounting systems for carbon emissions associated with various forms of energy generation are still evolving. In Oregon, further study is warranted to refine understanding of inter-related carbon implications of wildfire fuel reduction, wildfire risk and severity, and utilizing residual forest biomass for energy.

Since the 1990's, numerous state and federal working groups have examined the potential of forest biomass energy, optimistic that it could help achieve multiple goals, such as stimulating demand for residues from fuels reduction and forest health improvement projects, and reducing climate impacts. Over time, appreciation of the complexity of these issues has grown, along with refinement in understanding of the conditions under which forest biomass burning could qualify as a "green" energy source. Among the most high profile issues associated with use of forest biomass to generate energy are those related to carbon emissions, carbon sequestration and carbon accounting, especially when comparing biomass to fossil fuels and other energy sources. Assessments of how biomass extraction and utilization fit into the carbon cycle are critical because they affect biomass utilization incentives and how federal agencies will account for and regulate carbon emissions from biomass energy generation.

One noteworthy recent study addressing these issues was completed by the Manomet Center for Conservation Sciences for the Massachusetts Department of Energy (Manomet Center for Conservation Sciences 2010). The study question most relevant to Oregon was this: *What are the atmospheric greenhouse gas implications of shifting energy production from fossil fuel*

sources to forest biomass? (The study also addressed potential biomass supplies, ecological impacts of increased biomass harvests on Massachusetts forests, and forest practice guidance related to forest biomass extraction.)

The Manomet study notes that policies encouraging development of forest biomass energy generally view biomass as a carbon neutral energy source. In this view, carbon emissions are considered part of a cycle in which forests growing would over time re-capture and sequester the carbon emitted by burning biomass for energy. Beginning in the 1990s, there has been growing realization that carbon cycle and atmospheric greenhouse gas implications of utilizing forest biomass for energy vary in complex ways, depending on the characteristics of the bioenergy combustion technology, the fossil fuel technology it replaces, and the biophysical and forest management characteristics of the forests from which the biomass is harvested. Also, whether or not forest biomass can be considered carbon-neutral depends to some degree on the timeframe under consideration.

Noting that forest biomass generally emits more greenhouse gases than fossil fuels per unit of energy produced, the Manomet study defined these excess emissions as the biomass *carbon debt*. Over time, re-growth of the harvested forest pays down this debt by removing carbon from the atmosphere, then at some future point begins to yield *carbon dividends* in the form of lower atmospheric greenhouse gas levels than would have occurred through use of fossil fuels to generate the same amount of energy. Full recovery of the biomass carbon debt and the magnitude of the carbon dividend depend on future forest management actions and natural disturbance events that influence how this recovery occurs. (Manomet Center for Conservation Sciences 2010. The carbon debt concept was introduced in several recent articles in *Science* magazine; e.g., Fargione and others 2008, Searchinger and others 2009.)

The Manomet study states that the initial level of carbon debt is a critical factor in determining the desirability of producing energy from forest biomass. Replacement of fossil fuels in thermal or combined heat and power (CHP) applications typically has lower initial carbon debts than is the case for utility-scale biomass electric plants because thermal and CHP technologies can convert biomass to useable energy more efficiently. Thus, the length of time to pay off the carbon debt and begin accruing a carbon dividend from biomass energy will be shorter for thermal and CHP technologies under the same forest management and harvesting scenarios.

The magnitude and timing of carbon debts and dividends are sensitive to how landowners manage their forests so the Manomet study modeled recovery of carbon in growing forests under a range of different management scenarios. The study found that switching to biomass begins to yield a carbon dividend within the first decade when oil-fired thermal and CHP capacity is replaced, and within 20-30 years when natural gas thermal is replaced. Under comparable forest management assumptions, dividends from biomass replacement of coal-fired electric capacity begin at approximately 20 years but carbon debts are still not paid off after 90 years when biomass replaces natural gas electric capacity. (Manomet Center for Conservation Sciences 2010.)

The main “take-home” message of the Manomet study is that when assessing the desirability of producing energy from forest biomass, policymakers should carefully consider the magnitude of near-term carbon debts and how long it might take to begin to accrue longer-term carbon benefits. This way of assessing forest biomass power has generated some discussion and controversy. After the *Science* magazine articles and the Manomet study illuminated some of the issues regarding carbon debts, the US Environmental Protection Agency (EPA) issued a call for additional information related to accounting for greenhouse gas (GHG) emissions from bioenergy (add citation). In a response to EPA’s call, Idaho’s Policy Analysis Group (PAG) questioned some of Manomet’s key assumptions and conclusions (O’Laughlin 2010).

After noting that “for greenhouse gas emissions accounting purposes the choice of when the carbon cycle begins and ends is...one of the keys to determining whether a ‘biomass carbon debt’ exists”, O’Laughlin (2010) criticizes the Manomet “debt-then-dividend” model for taking “...the continuous process of carbon cycling over the entire earth and reduc[ing] it to one stand of trees over a discrete period of time that is relatively short (40-90 years) considering the life of a tree” (p. 42) and points out that “...the carbon cycle does not begin at the time a tree dies, rather it is continuous; wood utilization requires many, many stands sustained over a long period of time, not one stand over four decades...(p. 1)”.

O’Laughlin (2010) lists other viewpoints on carbon cycle timing and biomass combustion emissions accounting: 1) the current US Dept. of Energy position that “...combustion of biomass from sustainable sources produces zero net emissions because it releases carbon that previously was stored in the atmosphere and then transferred to vegetation through photosynthesis and CO₂ uptake before its release”, and 2) the emerging view in Europe that “...forest residues used for bioenergy immediately improve GHG emissions; so does wood from land converted from low carbon stocks to plantations, but these sources are not “carbon neutral” (Zanchi and others 2010). O’Laughlin (2010) summarizes the Manomet position that a “biomass carbon debt” exists for any reduction of existing forest carbon stock pools resulting from bioenergy combustion, including forest residues, and that this “debt” is not recovered or paid back until such time as forest growth recaptures the carbon released by biomass combustion”.

O’Laughlin (2010) argues that in contrast to the Manomet characterization, “carbon cycling between terrestrial ecosystems and the atmosphere occurs continuously...selecting the time a forest is harvested to begin counting carbon is arbitrary. It could just as easily begin when the trees were born rather than when they die.” (P. 21.) In this view, burning forest biomass incurs no carbon debt because carbon that trees pull out of the atmosphere as they grow is simply returned to the atmosphere when the biomass is burned, and will again be pulled out of the atmosphere as new trees grow. O’Laughlin (2010) further notes that across the landscape, managed forests are in various stages of growth, from early seral stage stands to mature forests with large trees that sequester significant amounts of carbon, and that it is thus necessary to account for carbon emissions and sequestration at the landscape-scale rather than at the stand level.

Strauss (2011) leveled criticism at the Manomet study for similar reasons to O’Laughlin (2010)- namely that the forest carbon cycle is continuous, that burning forest biomass is therefore “carbon neutral”, and that the Manomet authors inappropriately and arbitrarily chose the present as the baseline time for beginning their carbon analysis.

In a rejoinder to O’Laughlin (2010), later also submitted as a response to Strauss (2011), Walker (2010) said this: "When the focus is on how today’s decisions to generate more energy from biomass will affect future GHGs, past forest growth is irrelevant. The two primary drivers of future GHG impacts are (1) the relative levels of GHG emissions per unit of energy production for biomass and fossil fuels and (2) the future rates of carbon change in the forest in the control and biomass scenarios. Whether we start today with larger or smaller forest carbon inventories will not affect the predicted level of GHGs in either scenario. By choosing today as the starting point for analysis, we are not ignoring the existence of the biogenic carbon cycle. We are simply reflecting the commonsense insight that decreases in forest carbon stocks resulting from the harvest of biomass, relative to what these carbon stocks would have been in the control scenario, can result in a greater share of earth’s biogenic carbon ending up in the atmosphere instead of the forest. To properly calculate the change in atmospheric levels of GHGs by switching to biomass from fossil fuels, ‘today’ is the correct starting point for analyzing the future environmental impacts and benefits of implementing a new policy." (p. 2.)

Lucier (2010), writing in the Society of American Foresters publication *The Forestry Source*, also criticized the Manomet study, focusing more on the spatial scope than the temporal scope of their analysis. According to Lucier (2010) “the fatal flaw...is Manomet’s invalid assumption that modeling harvested stands in isolation is equivalent to modeling forests comprising a diverse population of stands. Manomet’s model of greenhouse gas emissions focuses only on stands of trees that are harvested in any given year and ignores stands that are not disturbed by harvesting...the model creates a false impression that forest carbon stocks are always depleted by harvesting; that biogenic CO₂ emissions from biomass energy systems are equivalent to carbon stock depletion due to biomass feedstock removals from harvested stands and that carbon stock depletion is reversed only gradually over a period of years by regrowth of the harvested stands. In real forests, changes in carbon stocks depend on rates of harvesting, growth, and mortality at larger spatial scales (e.g., landscapes or regions). In any given year, carbon stock depletion on harvested stands is offset to some degree by carbon accumulation on stands that are not disturbed.” (P. 4.)

In a rejoinder to Lucier (2010), the principal developers of Manomet’s carbon accounting approach agreed that carbon accounting should occur at the landscape level: “the only way to properly evaluate the net carbon impacts of energy from forest biomass is to estimate *at the landscape level* the net change in atmospheric CO₂ levels over time *with* and *without* the harvest of wood biomass for energy” and maintained that Manomet study did exactly that (Cardellicchio and Walker 2010, emphasis in original). Cardellicchio and Walker (2010) explain that the Manomet approach was to compare a baseline (no biomass harvest) scenario with a biomass harvest scenario to estimate the change in biomass-energy GHG emissions relative to emissions of the displaced fossil fuel and then measuring the difference in forest carbon stocks

between the biomass scenario and baseline scenario over time. From this perspective, they say, the spatial scale of the analysis becomes irrelevant because the stands that are not harvested in any time period have the same growth and inventory levels in both the biomass and baseline scenarios. Since there is no difference in carbon accumulation on unharvested stands between the two scenarios, the unharvested stands have no *net* effect on atmospheric carbon levels. By contrast, say Cardellichio and Walker (2010), Lucier (2010) counted carbon stock growth on acres that would have accumulated carbon anyway—implicitly assuming that current forest carbon stocks are the appropriate baseline. Cardellichio and Walker (2010) argue that Lucier (2010) is incorrect in suggesting that as long as stocks across the landscape remain stable or rise in the future, harvesting biomass for energy on a portion of the area will not increase atmospheric CO₂. They conclude by saying that the net impact on the atmosphere of burning wood for energy cannot be determined solely by tracking forest carbon stocks. Whether forest inventory is increasing, decreasing, or holding steady cannot by itself serve as a useful indicator of the net impacts on the atmosphere of switching to biomass energy.

The Manomet study has generated much discussion of its findings regarding biomass energy and carbon accounting, and provides an interesting framework for analyzing the timeframe over which these issues are analyzed. However, the Manomet study did not appear to address issues associated with how biomass extracted as part of fuels reduction projects affects wildfire risk and severity. As Wiedinmyer and Neff (2007) note “a striking implication of very large wildfires is that a severe fire season lasting only one or two months can release as much carbon as the annual emissions from the entire transportation or energy sector of an individual state.” There is ongoing discussion regarding the extent to which fuels reduction can reduce the amount of forestland burned in wildfires, because most acreage burns in a few very large fires that occur during periods of extreme weather conditions (Reinhardt and others 2008). But if the amount of carbon emitted when forest biomass burns in wildfires can be reduced by an amount greater than the amount of carbon emitted as a result of fuels removed and utilized for biomass energy, the net effects on carbon of forest biomass utilization may differ from the findings in the Manomet study. For conditions in Oregon, it would be relevant and informative to include scenarios that address the potential of fuels reduction to reduce the severity and scope of wildfires in analyses of carbon effects of utilizing forest biomass for energy.

Hudiburg and others (2011) addressed some of the same issues as did the Manomet study, but focused on the western US. Additionally, Hudiburg and others (2011) attempted to account for the potential of forest biomass removal to reduce carbon emissions from wildfires. They state that although forest thinning can be economically feasible, sustainable, and an effective strategy for preventing wildfire where risk is high, it remains unresolved whether this type of forest treatment can satisfy both the aims of preventing wildfire and reducing regional greenhouse gas emissions. For both aims to be satisfied, they say, it needs to be shown that: (1) reduction in carbon stocks due to thinning and the associated emissions are offset by avoiding fire emissions and substituting fossil fuel emissions with forest bioenergy, (2) the change in management results in less CO₂ emissions than the current or ‘baseline’ emissions, and (3) short-term emission changes are sustained in the long term.

Hudiburg and others (2011) studied 80 forest types in 19 ecoregions. In addition to current management or Business-As-Usual (BAU, characterized by current preventive thinning and harvest levels), they designed three treatments to reflect the varying objectives of potential forest management systems: forest fire prevention by emphasizing removal of fuel ladders ('Fire Prevention') in fire-prone areas, making fuel ladder removal economically feasible by emphasizing removal of additional marketable wood in fire-prone areas ('Economically Feasible'), or thinning all forestland regardless of fire risk to support energy production while contributing to fire prevention ('Bioenergy Production'). Removals are in addition to current harvest levels and are performed over a 20-year period such that 5% of the landscape is treated each year.

Hudiburg and others (2011) found that the current carbon sink in 16 of the 19 ecoregions is sufficiently strong that it cannot be matched or exceeded through substitution of fossil fuels by forest bioenergy. Regionally, forest biomass removals in most ecoregions exceeded the potential losses from forest fires, reducing the in situ forest carbon sink even after accounting for regrowth. The exceptions where the annual net change of land-based forest carbon was not reduced were primarily due to high initial fire emissions, such as the North Cascades. Because they assumed high reductions in fire emissions for the areas treated in each scenario, the authors maintain that it is unlikely they underestimated the benefit of preventive thinning on the annual net change of land-based forest carbon. But Hudiburg and others (2011) also note that if fire frequency and intensity increase in the future, emissions savings through forest bioenergy production may become possible in more of these ecoregions, especially those where the carbon sink is already weak. And in three ecoregions, Hudiburg and others (2011) found that immediate implementation of fire prevention and biofuel policies may yield net carbon emission savings. The authors conclude that forest policy should consider current forest carbon balance, local forest conditions and ecosystem sustainability in establishing how to decrease carbon emissions.

Richards (1997) lays out some precursors to the Manomet approach to understanding carbon implications of forest biomass energy in a discussion of the "time value" of carbon. In this view, the cost or value of carbon emitted or sequestered varies depending on when that carbon is emitted or sequestered. Carbon that is emitted or sequestered in the near term likely has a higher cost or benefit than carbon that is emitted or sequestered farther into the future. The exact discount rate that should be applied depends on the policy context of the analysis and other factors. Richards (1997) argues that accurate cost-benefit or cost effectiveness analyses of carbon, climate and energy policies require some means of accounting for the fact that carbon emission reductions and sequestration occur over periods of many years or even decades.

A related issue is the challenge of valuing carbon sequestration that is not permanent, such as carbon stored in growing forests. Marshall and Kelly (2010) summarize the issue as follows:

[Begin quote] *"As potential designs for climate legislation are debated in the United States, one central area of discussion has been about the extent to which*

the agricultural and forestry sectors can or should be involved as a source of offset credits for capped sectors under a climate bill. Offset credits represent reductions in an uncapped sector that can be sold into a capped sector and substituted for required reductions. Proponents argue that there are many sources of 'low hanging fruit' within agriculture and forestry where sequestration could occur at relatively low cost and that such reductions would help keep the costs of compliance with climate legislation low within the capped sector while providing additional income opportunities for the agricultural and forestry sectors.

Some policymakers are particularly enthusiastic about the potential for sequestering carbon in terrestrial ecosystems through an increase in biomass or soil organic carbon (van Kooten 2008). Such offset opportunities, termed "biological" or "sequestration" offsets, differ fundamentally from other potential offset opportunities within agriculture, however. Offsets generated from the use of methane digesters, changes in fertilizer use, and other agricultural practices represent emissions reductions that are permanent; future changes in practices will not re-emit the carbon reductions achieved through use of the technology or practice. Biological sequestration projects can make no such guarantee. Forests grown this year for sequestration purposes, for instance, could be harvested in 30 years if timber market prices change or could accidentally burn and release stored carbon as a result of natural processes. Because biological sequestration cannot guarantee permanent storage, it is difficult to define how such biological offsets "stack up" against permanent reductions in meeting emissions reductions goals for climate policy. Defining some measure of equivalence between permanent reductions and biological offsets, however, is critical to designing offset markets that allow one to be traded for the other.

The "permanence" issue in the biological offsets debate addresses the question of how policy can be designed to ensure that activities that are inherently impermanent can generate offset credits that are considered equivalent, by some definition, to permanent reductions. Proposed institutional design solutions to this problem have included: permanent enforcement, continuous liability rules, credit discounting, ton-year accounting, minimum period for project lifetime, temporary 'Certified Emissions Reductions' (CERs), buffers for risk management, and annually rented credits of some kind (Blanco and Forner 2000; Fearnside 2008; Sedjo and Marland 2003; Bigsby 2009)." [End quote, Marshall and Kelly (2010) pp. 11-13.]

Ager and others (2010, see also Cathcart and others [2010]; Kelly and Cathcart [2010]) addressed the issue of how fuels reduction affects wildfire probabilities and carbon emissions. They used wildfire simulation modeling to examine whether fuel reduction treatments can potentially reduce future wildfire emissions and provide carbon benefits. In contrast to previous reports, this study modeled landscape scale effects of fuel treatments on fire spread

and intensity, and used a probabilistic framework to quantify wildfire effects on carbon pools to account for stochastic wildfire occurrence. The study area was a 68,474 ha watershed located on the Fremont-Winema National Forest in SE Oregon. Fuel reduction treatments were simulated on 10% of the watershed (19% federal forestland). The researchers simulated 30,000 wildfires with random ignition locations under both treated and untreated landscapes to estimate the change in burn probability by flame length class resulting from the treatments. Carbon loss functions were then calculated with the Forest Vegetation Simulator for each stand in the study area to quantify change in carbon as a function of flame length. The researchers then calculated the expected change in carbon from a random ignition and wildfire as the sum of the product of the carbon loss and the burn probabilities by flame length class. The expected carbon difference between the non-treatment and treatment scenarios was then calculated to quantify the effect of fuel treatments.

Overall, results showed that the carbon loss from implementing fuel reduction treatments exceeded the expected carbon benefit associated with lowered burn probabilities and reduced fire severity on the treated landscape. Thus, fuel management activities resulted in an expected net loss of carbon immediately after treatment. However, Ager and others (2010) explain that these findings represent a point in time estimate, i.e. the chance of wildfire immediately after treatments and resulting carbon effects. They argue that, to provide better estimates of carbon effects over time, a temporal analysis with the probabilistic framework used here is needed to model carbon dynamics over the life cycle of the fuel treatments. Particularly important, they say, is the long-term balance between emissions from decay of dead trees killed by fire and carbon sequestration by forest regeneration following wildfire. It is also important to note that if wildfire risk changes over time, this will affect the outcomes of the carbon analysis. For example, higher wildfire risk could result in a higher probability of carbon benefits from fuels reduction treatments. (A. Ager, personal communication, 5-31-2011.)

The approach utilized by Ager and others (2010) shows promise for shedding light on where fuels projects would, and would not provide carbon sequestration benefits over time. A study using this methodology that included scenarios in which some or all of the forest biomass residues from fuels treatments were burned to provide biomass power might provide additional useful information.

Mitchell, Harmon and O'Connell (2009) explored trade-offs between reducing fuel (and therefore carbon[C]) that has accumulated through a century of fire suppression and exclusion which has led to extreme fire risk in some areas, and managing forests for enhanced C sequestration as a method of reducing atmospheric CO₂ and associated threats from global climate change. The researchers used a forest ecosystem simulation model, STANDCARB, to examine the effects of fuel reduction on fire severity and resulting long-term C dynamics among three Pacific Northwest ecosystems: east Cascades ponderosa pine forests, west Cascades western hemlock–Douglas-fir forests, and Coast Range western hemlock–Sitka spruce forests.

The simulations indicated that fuel reduction treatments in these ecosystems consistently reduced fire severity. However, reducing the fraction by which C is lost in a wildfire requires removal of a much greater amount of C, since most C stored in forest biomass (stem wood, branches, coarse woody debris) remains unconsumed even by high-severity wildfires. For this reason, all fuel reduction treatments simulated for west Cascades and Coast Range ecosystems and most treatments simulated for the east Cascades resulted in a reduced mean stand C storage. The authors note that one suggested method of compensating for such losses in C storage is to utilize C harvested in fuel reduction treatments as biofuels, but their analysis indicated that this would not be an effective strategy in the west Cascades and Coast Range over the next 100 years. Mitchell, Harmon and O'Connell (2009) suggest that forest management plans aimed solely at ameliorating increases in atmospheric CO₂ should forgo fuel reduction treatments in these ecosystems, with the possible exception of some east Cascades ponderosa pine stands with uncharacteristic levels of understory fuel accumulation. They conclude that balancing a demand for maximal landscape C storage with demand for reduced wildfire severity will likely require treatments to be applied strategically throughout the landscape.

Mitchell, Harmon and O'Connell (2009) examined a range of fuels treatments: salvage logging, understory removal, prescribed fire, understory removal plus prescribed fire, understory removal plus prescribed fire and overstory thinning, and understory removal plus prescribed fire and overstory removal. They also included a range of retreatment frequencies; 25, 10 and 5 years for eastern Cascades ecosystems. They found that fuel reduction treatments in east Cascades simulations reduced total ecosystem carbon (TEC) with the exception of understory removal, which occasionally resulted in additional C storage compared to the control. These differences were very small (0.6–1.2% increase in TEC) but statistically significant for the treatment return interval of 10 years in the light fire severity regime No. 1 (Mean Fire Return Interval = 8 years) and for all treatment return intervals in light fire severity regime No. 2 (Mean Fire Return Interval = 16 years).

Simulations of east Cascades ponderosa pine ecosystems had cases where stands treated with understory removal stored more C than control stands, implying that in certain cases there is little or no trade-off in managing stands of the east Cascades for both fuel reduction and long-term C storage. Mitchell, Harmon and O'Connell (2009) surmised that in these cases, simulated removal of highly flammable understory vegetation led to a reduction in overall fire severity that consequently lowered overall biomass combustion, thereby allowing increased overall C storage. They argue that this may be indicative of actual behavior under field conditions, but the very low magnitude of the differences between the treated and control groups (0.6%–1.2%) suggests caution in assuming that understory removal in this ecosystem can be effective in actually increasing long-term C storage. The authors state that the modeled differences between treated and control groups that were statistically significant probably overestimate the differences between groups that would occur in the field. Field-based estimates are more likely to exhibit higher inter- and intrasite variation than modeled estimates. The authors maintain that their general findings, however, are nonetheless consistent with prior field-based research on the effects of fuel reduction on C storage, though differences between modeled

and field based estimates are also undoubtedly apparent throughout other comparisons of treated and control stands in their study.

Mitchell, Harmon and O'Connell (2009) acknowledge that the extent to which fuel reductions in these forests can result in a reduction in fire severity during the extreme climate conditions that lead to broad-scale catastrophic wildfires may be different from the effects shown by their modeling results, and are likely to be an area of significant uncertainty. With the possible exception of some dry forest ecosystems in the east Cascades, they suggest that fuel reduction treatments should be forgone if forest ecosystems are to provide maximal amelioration of atmospheric CO₂ over the next 100 years. They agree that fuel reduction treatments may be essential for ecosystem restoration in forests with uncharacteristic levels of fuel buildup, as is often the case in the dry forest ecosystems of the east Cascades. However, they maintain that west-side forests are likely still within their historic fire return intervals, and that fires may result more from extreme weather events than fuel buildups in these forests. Thus fuels reduction may be ineffective at reducing fire risk in west-side forests, and is counterproductive from a carbon standpoint.

Disturbances in forest ecosystems can alter ecosystem carbon dynamics, often by reducing carbon uptake and stocks. Dore and others (2010) compared the impact of two types of disturbances that represent the most likely future conditions of currently dense ponderosa pine forests of the southwestern United States: (1) high-intensity fire and (2) thinning, designed to reduce fire intensity. They found that high severity fire had a larger impact on ecosystem carbon uptake and storage than thinning. Total ecosystem carbon was 42% lower at the intensely burned site, 10 years after burning, than at the undisturbed control site. Measurements over two years showed that the burned site was a net annual source of carbon to the atmosphere whereas the undisturbed site was a sink. Net primary production (NPP), evapotranspiration (ET), and water use efficiency were lower at the burned site than at the undisturbed site.

In contrast to high-intensity fire, thinning decreased total ecosystem carbon by 18%, and changed the site from a carbon sink to a source in the first post-treatment year. Thinning also decreased ET, reduced the limitation of drought on carbon uptake during summer, and did not change water use efficiency. Both high-intensity fire and thinning disturbances reduced ecosystem carbon uptake by decreasing gross primary production (55% by burning, 30% by thinning) more than total ecosystem respiration (TER; 33–47% by burning, 18% by thinning), and increased the contribution of soil carbon dioxide efflux to TER. The relationship between TER and temperature was not affected by either disturbance.

Dore and others (2010) conclude that efforts to accurately estimate regional carbon budgets should consider impacts on carbon dynamics of both large disturbances, such as high-intensity fire, and the partial disturbance of thinning that is often used to prevent intense burning. Their results show that thinned forests of ponderosa pine in the southwestern United States are a desirable alternative to intensively burned forests to maintain carbon stocks and primary production.

Woody biomass waste is generated throughout California from forest management, hazardous fuel reduction, and agricultural operations. Open pile burning in the vicinity of generation is frequently the only economic disposal option. Springsteen and others (2011) describe a framework to quantify air emissions reductions for projects that alternatively utilize biomass waste as fuel for energy production and a demonstration project that involved the grinding and 97-km one-way transport of 6096 bone-dry metric tons (BDT) of mixed conifer forest slash in the Sierra Nevada foothills for use as fuel in a biomass power cogeneration facility.

Compared with traditional open pile burning for disposal of the forest harvest slash, Springsteen and others (2011) calculated that utilization of the slash for fuel reduced particulate matter (PM) emissions by 98% (6 kg PM/BDT biomass), nitrogen oxides (NO_x) by 54% (1.6 kg NO_x/BDT), nonmethane volatile organics (NMOCs) by 99% (4.7 kg NMOCs/BDT), carbon monoxide (CO) by 97% (58 kg CO/BDT), and carbon dioxide equivalents (CO₂e) by 17% (0.38 t CO₂e/BDT). They state that emission contributions from biomass processing and transport operations were negligible. The largest source of uncertainty in the comparative analysis is emissions from biomass open pile burning, which can vary depending on woody biomass chemical composition (moisture, ash), physical characteristics (pile packing size and arrangement, biomass particle size), and atmospheric conditions (temperature, humidity, wind speed). Springsteen and others (2011) maintain that variability in the biomass open pile burn emissions factor will impact the magnitude of the emission reductions, but it will not alter the conclusion that emissions from the biomass energy project are lower compared with open pile burning.

Springsteen and others (2011) found that the biomass project significantly reduced the utilization of fossil fuels. They calculated that the project required 511 megajoules (MJ) of diesel fuel per BDT of forest biomass, but displaced the need for 9806 MJ of natural gas per BDT of biomass for electricity generated by the biomass-fired cogeneration facility. Energy benefits would be greater if the fossil fuel energy required to collect, refine, and deliver fossil fuel to market (with added fossil fuel energy penalty on the order of 20%) was considered. They note that carbon dioxide emission benefits are dependent on the emission characteristics of the displaced marginal electricity supply, and that benefits will be much greater for projects in regions where coal firing is predominant. NO_x benefits depend somewhat on biomass boiler performance. NO_x reductions will be significantly greater than in the demonstration program for low NO_x emitting systems including emerging technologies such as gasification, pyrolysis, and fuel cells and recently constructed or modified biomass boilers that use selective catalytic reduction.

The results of Springsteen and others (2011) suggest that in cases where forest slash or residues from fuels reduction projects would otherwise be certain to be open burned, utilizing this waste as biomass energy fuel could provide significant air quality benefits.

Lee and others (2010) completed a report requested by the regional air directors from the U.S. EPA Region 10 to analyze the life cycle air emissions of options for utilization of woody biomass

residues generated from forest practices in the PNW and Alaska (hereinafter termed SEI report). The research was funded by the U.S. EPA Region 10, managed by the Olympic Region Clean Air Agency (ORCAA) and prepared by the Seattle, WA based staff of the Stockholm Environment Institute (SEI) in collaboration with a Technical Advisory Committee made up of staff from the U.S. EPA Region 10, Washington State Department of Ecology, Washington State Department of Natural Resources, Olympic Region Clean Air Agency, Washington State University and representatives from Grays Harbor Paper LLC.

The SEI report notes that in the Pacific Northwest woody biomass residues from forest practices are most commonly burned on-site or left to decay, but air quality and climate concerns have increased interest in examining alternatives for managing these residues. The SEI analysis begins just after timber is harvested and woody biomass residues are generated and ends with its ultimate use or disposal. The report accounted for emissions associated with gathering, processing, transport, use and disposal of woody biomass residue. It also accounted for air emissions associated with manufacturing the equipment used to harvest, process and transport the woody biomass (e.g., loaders, grinders and transport vehicles). Emissions and/or carbon sequestration associated with forest management practices (e.g., harvesting, planting, and growth) are assumed to be identical for a given source of residues being compared and are by design not included in this analysis. The study quantified and compared “post-harvest to grave” air emissions from alternatives for woody biomass residues and was not intended to account for air emissions over the entire woody biomass life cycle nor evaluate the sustainability of wood bioenergy or carbon sequestration implications of different forest land management practices.

Net greenhouse gas (GHG) emissions results for each of 15 alternative fates were considered. The SEI report found that several fates studied resulted in net GHG emissions well (20% or more) below on-site combustion or on-site decomposition, including biochar (pyrolysis of biomass to make charcoal and generate electricity), displacing a fossil fuel boiler, integrated gasification and combustion (IGC), cogenerator, pulp and ethanol. All of these fates involved displacing fossil fuel use with biomass residue use. Cases where use of an EPA-certified wood or pellet stove avoids the use of fossil fuels also result in net GHG emissions well below on-site burning or decomposition. The more energy generated from woody biomass and the higher the emissions intensity of the fossil fuel displaced, the greater the net GHG emission reduction compared to on-site burning or decomposition. Use of woody biomass in an industrial boiler for heat production generates more energy per bone-dry ton (BDT) of woody biomass residue fuel and would displace more fossil energy resulting in net GHG emissions lower than any other fate considered.

The SEI report found that cases where woody biomass residues displace an existing wood source did not significantly reduce net GHG emissions relative to on-site burning or decomposition. Even for cases where the end use is decay, as in mulch and compost, net GHG emissions are slightly greater than on-site decomposition because there are emissions from pre-processing and distribution. For cases where the end use is combustion, as in hog fuel

boiler or residential energy, the net GHG emissions are very similar to on-site burning and vary depending on the alternate use emissions of existing wood sources.

The SEI report found that burning biomass at industrial facilities with emissions controls produces carbon monoxide (CO) and fine particulate matter (PM) emissions that are much lower than from uncontrolled burning on-site. For these fates, including biochar, displace fossil fuel boiler, displace hog fuel boiler, IGC, cogenerator, and pulp, use of residues results in a large reduction in CO (93% or more) and PM (85% or more) emissions compared to on-site combustion. Biomass combustion is a larger source of CO and PM emissions than fossil fuel combustion. As a result displacement of fossil fuel provides a little reduction in CO and PM emissions.

The SEI report found that for residential energy use fates CO and PM emissions vary by stove type. Emissions from fireplaces and EPA-certified stoves emit 4 times more CO and 6 times more PM per BDT than pellet stoves. CO and PM emissions are higher per BDT from fireplaces and EPA-certified wood stoves than from on-site burning. Net CO and PM emissions for residential energy fates vary depend on the displaced existing energy product. Net CO and PM emissions are lowest if the existing fuel wood source is diverted to on-site decomposition and no burning occurs. Mid-range net CO and PM emissions result where existing fuel wood is diverted to on-site burning. The highest net CO and PM emissions occur if fossil fuel is displaced or existing fuel wood is used in an EPA-certified stove. Similar to industrial energy fates, CO and PM emissions from fossil fuel use for residential energy are much smaller than wood energy use. As a result displacement of fossil fuel provides a limited reduction in net CO and PM emissions for residential energy fates. Overall the largest reduction in net CO and PM emissions, compared to on-site burning or decomposition, occurs when pellet stove use replaces existing use of an EPA-certified stove and existing fuel wood is left to decay.

The SEI report authors summarized their findings as follows:

GHG emissions:

- GHG emissions from pre-processing of residues, including the gathering, chipping and transporting residues from the harvest site to a processing facility make up less than 4% of system emissions
- Use of woody biomass residues to displace the use of fossil fuels provides the greatest reduction in net GHG emissions relative to the common practices of on-site combustion and on-site decomposition.
- The net GHG emissions for woody biomass residues that displace fossil fuels vary depending on the how efficiently residues are used as an energy source and the fossil fuel type displaced. Reductions in net GHG emissions are greatest for the fates with a higher energy output per BDT (e.g., industrial boilers) and lowest for the less efficient processes like generating ethanol via gasification.

- Use of woody biomass residues to displace existing wood and organic products results in a minimal change in net GHG emissions from the common practices of on-site combustion and on-site decomposition.

CO and PM emissions:

- Use of woody biomass residues for a fireplace or EPA-certified stove results in an increase in CO and PM emissions relative to the common practices of on-site combustion and on-site decomposition. The only exception is when existing fuel wood is diverted to on-site decomposition and no combustion of the displaced fuel wood occurs. Compared to on-site combustion, emissions from fireplace and wood stove use are much more likely to occur near populated areas.
- Use of woody biomass residues for residential energy in pellet stoves results in a decrease in CO and PM relative to the common practices.
- Use of woody biomass residues for soil amendment, industrial energy, industrial feedstock and liquid fuel all result in large net CO and net PM reductions relative to the common practice of on-site combustion.
- Use of woody biomass residues for liquid fuel to displace gasoline provides the largest net CO emissions benefit from fossil fuel displacement.
- Use of woody biomass residues for industrial energy to displace residual oil provides the largest net PM emissions benefit from fossil fuel displacement.

Morris and others (2010) prepared a detailed critique of the SEI report and provided the critique to the reviewers of the original report, as well as to the report authors. Morris and others (2010) asserted that errors, omissions, biased assumptions and limited perspective of SEI study will result in policy decisions promoting biomass combustion and gasification that will have impacts on climate, human health and ecosystems that are more deleterious than study conclusions suggested. They further asserted that SEI's emissions estimates for important air pollutants and their conclusions are at odds with scientific literature, and that data was cherry picked and information omitted.

Before discussing each point in more detail, Morris and others (2010) summarized their criticisms as follows:

“SEI's life cycle assessment (LCA) of management alternatives for logging residues contains serious errors, omits several viable alternatives, and is based on assumptions and oversimplifications that bias the analysis against non-combustion uses for woody biomass residues. These biased assumptions, oversimplifications, errors, and omissions include:

- a. Oversimplified and biased characterizations regarding the markets for products and energy that can be produced from logging slash.
- b. Restricting the LCA to exclude benefits of reduced tree harvest which result from management methods such as conversion to papermaking pulp or engineered wood products.

- c. Failure to analyze life cycle emissions for alternative uses such as engineered wood applications and landfill daily cover that are as technologically feasible and economically viable as alternative uses such as IGC that are analyzed.
- d. Unsupported assumptions that IGC PM emissions are equivalent to natural gas and that IGC CO emissions are essentially zero.
- e. Omission of emissions estimates for black carbon, nitrogen oxides, volatile organic compounds (VOCs), heavy metals or hazardous air pollutants.
- f. The biasing assumption that emissions from construction of new stationary facilities for combustion or integrated gasification and combustion of logging residues are outside the study's scope.
- g. The biasing assumption that instantaneous GHG emissions from combustion have the same climate impact as an equivalent quantity of cumulative emissions from decomposition that are slowly released over scores of years.
- h. Omission of the carbon storage and enhanced carbon sequestration benefits when slash is left to decompose at the logging site or when soils are amended with compost or mulches that incorporate slash." (End quote, pp. 2-3.)

4. Effects of woody biomass collection and conversion on soil resources

Key findings for soil resources:

- a. Decomposition of down woody material improves the physical and chemical characteristics of forest soils over time by enhancing soil organic matter and nutrient content, and by increasing rates of nutrient uptake through associations with ectomycorrhizal fungi.
- b. Forest biomass removal can benefit wildlife, and forest health and productivity, but must be balanced with the need to ensure that sufficient biomass remains onsite to meet habitat needs, replenish soil resources and maintain ecosystem processes.
- c. Increasing biomass utilization may result in greater use of whole-tree removal harvesting systems. Due to the high nutrient concentration in branches, leaves, and roots, it is essential to ensure that biomass harvesting does not mine the long-term site nutrient capital.
- d. The impact on soil nutrients from biomass removal is site dependent. Coarse-textured, low-nutrient sites are much more likely to be damaged by intensive biomass removal than sites with finer soils, higher nutrient capital or more rapid nutrient inputs.
- e. Thinning operations are less likely to cause significant soil compaction, and less likely to deplete the quantity and diversity of ectomycorrhizal fungi than a stand-removal harvest.

One issue associated with the removal of woody biomass from forests is the effect this may have on forest soil nutrients. Some are concerned that removing organic material that would

otherwise decompose onsite in forests might eventually reduce the biological productivity of those forest sites. A related concern is potential impacts on soil microorganisms such as ectomycorrhizal fungi that contribute to forest health and productivity. Some studies that address these issues are paraphrased below.

The 2010 Pinchot Institute for Conservation study entitled “Forest Sustainability in the Development of Wood Bioenergy in the US” (Sample and others 2010) includes a discussion of down woody material (DWM) and soil productivity effects associated with forest biomass harvesting. The following material quoted from Sample and others (2010) pertains to the maintenance of soil productivity:

“While forest health thinnings can often be a positive management tool for wildlife habitat and forest health and productivity, there is a balance between removing more dead and dying standing trees and ensuring that there will be sufficient DWM in the future to maintain ecosystem processes....When harvesting biomass it can sometimes be difficult to distinguish between preexisting DWM and newly created logging slash, and in some areas, it is common practice to treat all this material the same through collection or disposal. This is standard practice in....forests where slash piles add to the risk of wildfire or insect infestation...however, this is certainly not the case for all forest types, and some suggest that biomass harvests pose a high level of risk to the forest floor and the forest structure, unless careful measures are taken (Bragg and Kershner 1999; Brown and others 2007; Janowiak and Webster 2010).

The size, shape, volume, composition, and location of DWM all play a role in wood decomposition and the cycling of nutrients in forest ecosystems (Harmon and others 1986; Wu and others 2005; Li and others 2007; Berg and McClaugherty 2008). Decomposition of DWM improves the physical and chemical characteristics of forest soils over time by enhancing soil organic matter and nutrient content, and by increasing rates of nutrient uptake through associations with ectomycorrhizal fungi (Harmon and others 1994; Hagan and Grove 1999; Hafner and others 2005). Fungi remove nutrients from DWM, making these nutrients available in forest soils. Many fungal communities have associations with certain tree species and even specific sizes of DWM. In general the diversity of fungal communities is an indicator of overall forest health and productivity. Studies in Sweden and Finland— two countries where biomass harvesting using whole tree removal systems is practiced widely—have measured significant loss in the abundance of liverworts and fungi in instances where DWM was removed during successive harvests (Amaranthus and others 1994; Stupak and others 2008).

When it comes to biomass harvesting, the maintenance of soil fertility and related forest productivity are two of the main areas of concern for managers. Risk of nutrient depletion is related to the quantity and type of material that is

removed during harvests. Provided that steps are taken to ensure that sufficient DWM is left on site and that regeneration will occur, most forests have the capability to restore site nutrients over time following harvests. However, this depends on a number of factors including soil type, forest type, climate, and management decisions. Due to the high nutrient concentration in branches, leaves, and roots, it is essential to ensure that biomass harvesting does not mine the long-term site nutrient capital. Subsequent unplanned and intensive harvests have the potential to negatively impact soil nutrient pools if these interventions are not timed appropriately to ensure that the soil nutrient capital is restored.

If biomass is to be harvested on a large scale many experts believe that increasingly mechanized whole tree removal systems will be employed much more often. While a more efficient means of tree removal, whole tree harvesting can reduce the long-term availability of soil nutrients, in part because a higher percentage of foliage and twigs, the above-ground parts of trees that contain the most nutrients, are transported off site, where they no longer contribute to forest nutrient pools. The results of several studies going back to the 1970s suggest that under certain conditions, whole tree clear cut harvesting techniques may lead to significant quantities of nutrients (up to 10 percent if there is no biomass retained on site) being directly removed and leached from forest soils (Huntington and Ryan 1990).

Even highly productive loblolly pine plantations on the...Gulf Coast experienced a loss of productivity following whole-tree harvesting clear cutting operations, with one long-term productivity study finding an average productivity reduction of 18 percent (Scott and Dean 2006). On intensively managed sites in Sweden and Finland, where clear-cutting with whole-tree harvesting systems was practiced in successive rotations, researchers noted a 10 percent drop in forest productivity (Amaranthus et al. 1994; Stupak et al. 2008; Mahendrappa and Salonijs 2006). The loss of forest productivity has led to recent regulations in Sweden requiring the application of wood ash in an attempt to ameliorate or prevent soil nutrient loss. Conversely, data collected over the first decade of the USDA Forest Service Long Term Soil Productivity study (LTSP) of 26 sites across the nation suggests that the removal of biomass during sawtimber harvests had no detectable influence on forest growth within the first 10 years following harvests (Powers and others 2005). Based on these conflicting studies there appears to be no scientific consensus on the risks that biomass harvesting practices present to nutrient cycling in forests, beyond the recognition that there is wide variability from site to site.” (End quote, Sample and others 2010, p. 13-14.)

Page-Dumroese (2010) and Page-Dumroese and others (2010) offer recommendations and findings derived from stand-removal studies that are also applicable to guide biomass thinnings for forest health, fuel reduction, or energy production: (1) thinning operations are less likely to cause significant soil compaction than a stand-removal harvest, (2) risk-rating systems that

evaluate soil susceptibility to compaction or nutrient losses from organic or mineral topsoil removal can help guide management practices, (3) using designated or existing harvesting traffic lanes and leaving some thinning residue in high traffic areas can reduce soil compaction on a stand basis, and (4) coarse-textured low fertility soils have greater risk of nutrient limitations resulting from whole-tree thinning removals than finer textured soils with higher fertility levels. Risk rating systems for soil susceptibility should account for soil nutrient pools, topography, aspect and local climate regimes.

Page-Dumroese (2010) further suggests harvesting forest biomass during periods when soils are at lower risk for compaction (i.e. when frozen or during dry season). Biomass removal should focus on coarser textured, larger diameter forest slash rather than finer textured forest floor litter that contributes to soil organic matter, which should be left in place and not disturbed. Stumps should be left in place because removing stumps disturbs soil, exacerbates erosion and stream sedimentation, and moves lower productivity subsoil to the surface horizon. (Page-Dumroese 2010.)

Outerbridge and Trofymow (2009) assessed ectomycorrhizal (EM) colonization in a variable green tree retention experimental block near Powell River, British Columbia. The authors note that while the importance of EM fungi in tree physiology is well documented, much EM fungi research has focused on their role in seedling establishment and growth. Less is known about their importance in long-term forest health. If EM fungi are significantly depleted (as is the case in many parts of Europe) forest health could decline, with significant ecological and economic impacts. Ectomycorrhizae are major contributors to nutrient dynamics and carbon cycling in forest ecosystems, important food sources for animals, and also produce many commercially important mushroom species.

In previous work on southern Vancouver Island, Canada the authors observed significantly lower abundance and diversity of EM fungi with increased distance from retained forest patches (Outerbridge and Trofymow 2004). This research was extended to examine how different levels of dispersed green tree retention affect EM colonization by measuring the effect of various treatments at an experimental variable retention block. Transects were established in treatments where 0% (clearcut), 5%, 10%, and 30% of trees were retained. Douglas-fir seedlings were planted at 5, 15, 25 and 45 m from the remaining forest edge and excavated 18 months later for analysis of EM colonization. Forest soil cores and sporocarp surveys provided information on EM species potentially available for colonization of seedlings. A total of 85 EM morphotypes were observed. Edge effects—declines with distance from the forest, observed in the 0% retention treatment—were diminished in the higher-retention treatments.

Results showed that the level of ectomycorrhizal diversity was related to the level of green tree retention, but there was not strong evidence that EM fungal response closely tracked a gradient across various tree retention levels. Examination of EM root colonization and morphotype richness on Douglas-fir seedlings suggested that increased level of tree retention translates into increased levels of EM diversity. There were significant differences in the EM

community on seedlings compared to adult trees. The authors recommend the highest level of green tree retention possible in actively managed forests, i.e. 30% or more depending on original stand density. The authors also note that despite ample sporocarp production, most EM fungi are more adapted to dispersing via vegetative mycelia in contrast to other fungi which disperse mainly by spores. Various EM fungi also have different rates of mycelial spread and different abilities to withstand temporary loss of host and environmental pressures. Root-to-root contact of host trees is of utmost importance for many EM species, so managers should try to maintain uninterrupted root-to-root contact in order to promote ectomycorrhizal fungal spread.

Dahlberg and others (2001) monitored the survival of ectomycorrhizal (EM) fungi as mycorrhizas, at a clear-cut, a seed tree stand and an uncut stand of Scots pine in central Sweden, with and without burning at two levels of fire severity. The abundance of mycorrhizas and the EM fungal diversity declined with increased logging intensity and with increased depth of burn. They found that deep burning fires in combination with logging or fire-caused tree mortality can kill much of the existing EM community. Dahlberg and others (2001) state that logging intensity, prescribed fire intensity and fire severity are all factors that can be manipulated, thus changing the effects on EM fungi and other soil biota.

Boyle and others (2005) evaluated the impacts of two replicated ecological restoration treatments involving tree thinning alone (thinning restoration) and a combination of tree thinning, forest floor reduction, and prescribed burning (composite restoration) on soil microbial activity, biomass, and function approximately 8 years after initial treatments in a northern Arizona ponderosa pine forest. Thinning reduced the stand basal area from ~35 to <13 m² ha⁻¹. About 50% of the trees removed were between 2.5 and 12.5 cm dbh. Results suggested that tree removal alone had only a modest impact on the soil microbial community 8 years after treatment. Soil respiration was significantly higher in the restoration treatments than in the control during the dry period, but similar to the control during the wet period. The higher soil respiration rate in the thinning treatment during the dry period was thought to result from higher soil temperatures in this treatment compared to the control. The authors conclude that, by itself, the thinning regime they examined likely does not have large effects on the function of the soil microbial community over the long term. In contrast, thinning combined with forest floor manipulations (i.e. removal of duff) and reintroduction of fire affected the physiological capacities of soil microflora, probably through changes in the availability of substrates. Differences in soil microbial activity and function among canopy types were also observed that were consistent regardless of treatment. This result suggests that over the long term the indirect effects of restoration treatments on vegetation composition may have a greater impact on the soil microflora than the direct effects of the treatments themselves.

Boyle and others (2005) note that many studies have shown that soil microbial activity is strongly related to water availability, and that inter-annual variability in water availability is extremely high in southwestern US ponderosa pine ecosystems, with very pronounced dry and wet periods. While central and eastern Oregon ponderosa pine forests may be similar in

appearance, they have a considerably different precipitation regime. Applicability of studies in conducted the southwest to ponderosa pine ecosystems in Oregon should be interpreted with this in mind.

The Forest Guild is a professional organization of forest stewards, natural resource professionals, and affiliates dedicated to restoring and sustaining the integrity of forests while meeting the needs of the communities that rely on them. The Forest Guild completed reviews on the ecology of dead wood in the northeastern US (Evans and Kelty 2010), and of state, federal and international policies and forest management practices pertaining to harvesting of forest biomass, including considerations for maintaining soil nutrients and productivity (Evans, Pershel and Kittler 2010). These reviews were funded by the Northern Forest Investment Zone of the U. S. Endowment for Forestry & Communities, the Massachusetts Department of Energy Resources as part of the Manomet Center for Conservation Sciences Biomass Sustainability and Carbon Policy Study, the Betterment Fund, and the Merck Family Fund. The reviews also appear as Appendices 4-A and 4-B in the Manomet Center for Conservation Sciences (2010) study for the Massachusetts Dept. of Energy Resources.

Aside from some mention of California, the Forest Guild/Manomet review of guidance for limiting environmental impacts of biomass removal was limited primarily to the northeastern, midwestern and southern US, eastern Canada, and northern Europe. Practices for minimizing the environmental effects of biomass removal in states in the Pacific northwest, intermountain west and southwestern US are not discussed. This is likely because while western states generally have detailed forest practice guidance in place, they have thus far developed few if any guidelines that pertain specifically to removal of non-merchantable biomass. (It is important to note that protection measures in place in western states generally also apply to biomass harvests.) The Forest Guild/Manomet reviews synthesize much relevant information, but could be supplemented with additional review and discussion of issues specific to Oregon and other western states. For example, issues in the western US regarding tradeoffs between 1) reducing the risk and impacts of uncharacteristically severe wildfire and, 2) management of forests to sequester carbon and mitigate climate change do not receive a thorough treatment.

Evans and Kelty (2010) found that scientific data suggests that when both sensitive sites (including low-nutrient) and clearcutting with whole-tree removal are avoided, then nutrient capital can be protected when removing forest biomass (see also Hacker 2005). However, they also note that there is no scientific consensus on this point because of the range of treatments and experimental sites (Grigal 2000). Evans and Kelty (2010) also reinforce the point that the impact on soil nutrients from biomass removal is site dependent. Low-nutrient sites are much more likely to be damaged by intensive biomass removal than sites with great nutrient capital or more rapid nutrient inputs.

Evans, Pershel and Kittler (2010) note that state forest practice guidelines usually address some aspects of soil productivity. But they point out that such guidelines are typically developed to address issues at a particular point in time. As new issues, resource uses and market forces emerge, additional guidelines may be necessary, depending on the adequacy of existing

guidance to protect forest resources. Thus, some states are also developing additional provisions specifically for biomass removal. For instance, Minnesota's biomass guidelines add warnings about harvesting biomass on bog soils and shallow soils (less than 8 inches) over bedrock. Wisconsin's guidelines include a list of ~700 specific soil map units which are nutrient poor and unlikely to be able to support sustainable biomass removal. Maine's guidelines use Briggs soil drainage classes to identify sites that are more sensitive to biomass removals. Michigan recommends leaving >33% of harvested tops on shallow, nutrient-poor or semi-organic soils, but suggests that retention can be reduced on jack pine stands on nutrient poor sites. Maine, Michigan, Minnesota, Pennsylvania, and Wisconsin's guidelines also state that forest floor, litter layer, stumps, and root systems should all be retained onsite. New Hampshire's existing guidance does not pertain specifically to biomass removal, but recommends identification of low fertility sites using soil maps and site descriptions, then using practices such as bole-only harvesting (leaving limbs and tops onsite), harvesting hardwoods only during leaf-off periods and limiting disturbance of organic soil layers. (Evans, Pershel and Kittler 2010.)

At the time the Forest Guild review was completed (2010) the Canadian provinces of New Brunswick and Quebec were in the process of developing biomass guidelines based on soil properties. Sweden specifies that forest residues should be dried before removal, so that needles are left onsite. But in-stand drying is prohibited in spring and early summer in Sweden and in other Nordic countries to reduce the risk of bark beetle infestation. Finnish guidelines for biomass harvesting suggest that 30% of residues should be left and distributed evenly across the site following clearcuts, and that wood ash be spread on peat land as a fertilizer after thinning, or if logging residues or stumps are extracted from nutrient-poor sites. Danish forest policy suggests that nutrients depleted by logging may be compensated for by fertilization, and that stumps are not to be removed. In the UK, it is suggested that site-specific risk assessments, including a soil test, should be conducted before each harvest, and sites are assessed for biomass harvest suitability based on the most sensitive soil type that covers greater than 20% of the site area. (Evans, Pershel and Kittler 2010.)

Johnston and Crossley (2002) integrated land-use history, pine ecology, silviculture, soil ecological research and the implications for forest management into a single discussion of the importance of recovering soils in areas relied upon by the forestry industry in the southeastern United States, with an emphasis on loblolly pine forests. The authors note that soils in these forests are often highly eroded and depleted of their original organic matter and nutrient content, and argue that proactive land management can ensure continued and possibly increased production and revenue through the management and recovery of the soil resource. They explain that promoting soil recovery involves knowledge of ecosystem history and disturbance as well as nutrient cycling mechanisms, pools, fluxes and soil forming factors. They argue that more research on the rhizosphere (the narrow region of soil zone surrounding the roots of plants that is directly influenced by root secretions and associated soil microorganisms) is needed and that recovery of regional soils may confer benefits of drought and disease resistance.

Johnston and Crossley (2002) further argue that the goal of sustainable forestry is compatible with soil recovery; but that the agricultural model of modern plantation forestry is much different from managing for healthy forest ecosystems. They maintain that practices of intensive forest management, including short rotations and burning or removal of logging slash, seem to be at odds with the goal of soil recovery and suggest best management practices for soil recovery including less intensive stand utilization, reduced soil disturbance, stem-only harvest and longer rotations to permit a recovery of soil biodiversity and an accrual of detritus and soil organic matter.

With regard to forest biomass removal and utilization in Oregon, suggestions made by Johnston and Crossley (2002) might apply to areas where past intensive management has degraded soils, or areas where soils are naturally nutrient poor.

5. Effects of woody biomass collection and conversion on wildlife resources

Key findings for wildlife:

- a. Identification of focal species or species of special concern in a particular fuels project area is a critical first step that can strongly influence the type and location of treatments. “Some species will gain and some species will lose habitat when stand structure or composition is changed during fuel reduction treatments.” (Lemkuhl and others 2007.)
- b. Thinning designed to promote species diversity will likely need locally tailored prescriptions of intensity and pattern. In general, diversity of treatments promotes diversity of species.
- c. For any fuels reduction project, special attention should be given to stream-dwelling amphibians which are particularly vulnerable to changes in thermal and sediment conditions that may result from thinning in riparian areas. Adequate stream buffers are especially important for amphibians.
- d. Thinning would likely benefit most species of reptiles.
- e. Maintenance of adequate amounts of down woody material (DWM) for wildlife may require additional attention from managers of projects that remove material formerly regarded as waste and left in the stand.

Wildlife – General

The 2010 Pinchot Institute for Conservation study entitled “Forest Sustainability in the Development of Wood Bioenergy in the US” (Alaric and others 2010) discusses down woody material (DWM) and soil productivity effects associated with forest biomass harvesting. The following section pertains to DWM:

“In forest ecosystems, the matrix of deadwood that is comprised of standing dead trees (snags) and down woody material (DWM) is an important structural characteristic. This material can range in composition, but usually consists of primary branches, stumps, trunks, tree tops, and

whole dead trees with upturned root wads. There are almost always more organisms inhabiting deadwood than live trees. As a major energy source in forest ecosystems, deadwood provides habitat and a food source for many invertebrates (e.g., arthropods, earthworms, and beneficial microbes) and terrestrial vertebrates (e.g., small mammals, amphibians, reptiles, and birds) (Harmon and others 1986; Hagan and Grove 1999). In general, managed forests are characterized by smaller quantities of DWM than unmanaged forests. Opportunities for accumulation of new DWM generally decrease as the time period between rotations decreases, and as more intensive harvesting practices (e.g., whole tree harvesting) are adopted (Lonsdale and others 2008). There is concern that forest biomass harvests will be more intensive than typical harvests and that this could alter the natural progression of DWM and negatively impact a variety of ecosystem service values.” (Sample and others 2010, p. 13.)

Verschuyf and others (2011) summarized documented relationships between forest thinning treatments and forest biodiversity from 505 biodiversity effect sizes (incl. taxa and guild abundance and species richness measures) from 33 studies conducted across North America. The 33 studies suitable for inclusion in the authors’ meta-analysis were those relative to effects of forest thinning on wildlife species that provided quantified results in the form of control and treatment means, sample size and standard deviations for biodiversity responses. Several otherwise suitable studies did not report standard deviations or standard error measures. Some publications provided treatment and control means with an associated two-sample t-test statistic, p-value and degrees of freedom. In these cases, Verschuyf and others (2011) used the pooled variance in place of individual treatment and control standard deviation measures. When neither standard deviation nor test-statistic/p-values were reported, the investigators were contacted and, when raw data were available, error values were calculated. If error measures could not be back-calculated and raw data were not available, the study was not included in the meta-analysis but was discussed qualitatively. Both manipulative experiments (wildlife diversity and abundance measured before and after thinning treatments) and management experiments (stands paired post hoc and thinned areas are compared to unthinned controls) were among the studies included. Controls presented in the included studies of precommercial, commercial, and fuels treatment thinning were most commonly unthinned harvest-aged stands (30–75 yrs old).

Verschuyf and others (2011) summarized biodiversity response by region, taxa and harvest treatments. Biodiversity responses included species richness, diversity, abundance of taxa or groups of species (guilds) and abundance of individual species for birds, mammals, reptiles, amphibians, and invertebrates. Their results showed that across most thinning intensities and forest types, forest thinning treatments had generally positive or neutral effects on diversity and abundance across all taxa, although thinning intensity and the type of thinning conducted may at least partially drive the magnitude of response. They found that the magnitude of response to forest thinning, either positive or negative, is often small. Verschuyf and others (2011) caution that some species of higher conservation concern may be either positively or negatively affected by thinning and that simple diversity and richness measures may not be sufficient for fully understanding the effects of thinning on biodiversity.

Verschuyf and others (2011) conclude with some points regarding the location-specific nature of biodiversity response to forest thinning. They point out that in highly productive systems with long periods between disturbances, a few species can begin to dominate the community, leading to lower diversity (Huston 1999, 2004; Odion and Sarr 2007). Forest thinning in highly productive forests may provide the disturbance necessary to counteract this “competitive dominance”. On the other hand, in less productive forests, more care may be needed to balance biomass harvest objectives with those for maintaining biodiversity (Janowiak and Webster 2010; Page-Dumroese and others 2010). Disturbance intensity and biophysical setting are likely to be strong determinants of response by wildlife and vegetation to biomass thinning harvests (Greenberg and others 2007a,b). Thinning designed to promote species diversity will likely need locally tailored prescriptions of intensity and pattern (Hagar and others 2004).

(Additional results and conclusions from Verschuyf and others (2011) are presented below under sections for plants, birds, mammals, reptiles and amphibians, and arthropods.)

Lemkuhl and others (2007) describe an approach to incorporating ecological values into fuels reduction projects at the stand and landscape levels. The authors note that because “uncertain ecological objectives... are more difficult to integrate into fuels management compared to the relatively simple and better known objectives and methods of fire and fuel management... fuel reduction programs tend to be oriented to fuels more than forest restoration, hence attract litigation or require extensive consultation on ecological effects, e.g., impacts on threatened or endangered species like the northern spotted owl.” (P. 74.) They suggest that more proactive identification and consideration of specific ecological values in the area where a fuels project is planned could help reduce conflict and the cost of such projects.

For the stand level, Lemkuhl and others (2007) use an example of an ecological web that includes the northern spotted owl, its two primary prey species the northern flying squirrel and bushy-tailed woodrat, and the vegetation (live and dead), mycorrhizal fungi, and arboreal lichens that support those prey species. For the landscape level, they describe an ongoing project to develop the FuelSolve computer tool that optimizes the area and location of fuel treatments that minimize potential fire behavior and minimize loss of spotted owl habitat from treatment and potential wildfire. The authors explain that the spotted owl habitat goal they used as an example could be generalized to model solutions for any ecological values that can be defined on a map.

Stand-level prescriptions might be altered to maintain or create patchiness of closed-canopy habitat elements, such as snags, down wood, mistletoe-infected trees, and large old trees, and open-canopy habitats can be tailored to ensure creation of suitable composition and structure for wildlife. Allocation of treatments across the landscape might be managed to minimize cumulative effects and impacts on target species populations. Landscape-level planning of ecologically sound fuel treatments could utilize coarse- and fine-filter approaches. A coarse-filter approach would use historical range of variability to define the composition and pattern that might reasonably be expected to sustain the forest ecosystem. Fine-filter assessment could include population viability analysis of focal or target species identified in a particular

area, based on attributes of the species population structure, life history and behavior, and habitat. Fine-filter analysis can be informed by operational modeling of treatment alternatives using tools that equally consider multiple optimization objectives for fuel treatment and ecologically important resources.

The suggestion by Lemkuhl and others (2007) that incorporating wildlife and other ecological considerations into fuels projects requires identification of location-specific focal species and conditions is also supported by one of Kennedy and Fontaines' (2009) findings. These latter authors conducted an extensive literature review of studies on fire and fire surrogate effects on wildlife for the Fire and Fire Surrogates (FFS) research program. Kennedy and Fontaine (2009) note that when results from studies on the same species but in different geographic areas are compared, "in many cases, the site effect overwhelmed any effect of treatment. This is likely caused by the extreme heterogeneity in pretreatment site conditions, which influenced the post-treatment site conditions." (P. 56.) As an example they cite results for the deer mouse to fuels treatments. At four of six sites, the deer mouse was a nonresponder to all treatments, but at one it was a positive responder to prescribed fire, a nonresponder to thin only, and a negative responder to the thin + burn treatment. At another site deer mice were positive responders to the thin-only treatment.

Kennedy and Fontaine (2009) conclude that because of this type of heterogeneity, making general prescriptive recommendations about wildlife population management was not possible based on their review of the literature. Thus, they suggest that managers who want to avoid negative impacts to a particular species from fuel-reduction treatments will need to determine which of a suite of possible treatments is most effective in their area. To develop this knowledge, projects may be implemented as scientific studies of testable hypotheses developed from available species-specific data (e.g., tables presented in Kennedy and Fontaine 2009). Species response to the treatments can then be monitored and this information incorporated into local knowledge and subsequent management (adaptive management).

Mechanical thinning and prescribed burning practices are commonly used to address tree stocking, spacing, composition, and canopy and surface fuel conditions in western US mixed conifer forests. Hessburg, Povak and Salter (2010) examined the effects of these fuel treatments alone and combined on snag abundance and spatial pattern across 12 10-ha treatment units in central Washington State. A snag census was conducted before and immediately after treatments on each unit where all snags were measured and classified as either "new" (<1 year as a snag) or "old" (>1 year as a snag) mortality and bark beetle species were censused on the bottom 3-m of the bole. Before treatment, snags were found in all units and more than two-thirds of the snags were ponderosa pine.

Thinning treatments were designed to reduce stand density and favor drought and fire-tolerant species (i.e., the largest ponderosa pine and Douglas-fir). Residual densities were targeted to fall within the estimated historical density and spatial distribution for the area (approximately 10–14 m²/ha at irregular spacing). Thinning was accomplished with chainsaw felling during the winter of 2002–2003. Merchantable logs were limbed after felling such that tops and branches

remained on site, and merchantable logs were helicopter-yarded to landings external to the study area. Nonmerchantable trees were also felled and left on site. Snag removal due to occupational safety and health concerns during the thinning operations was required, which may have precluded meeting snag stocking requirements in portions of some units.

Burning (burn-only and thin -burn combined) treatments led to increases in total snag abundance in all but the largest diameter class. Snag abundance in the large snag class (>60 cm dbh) decreased in most treatment units indicating that units with high abundance before treatment had the potential to lose more snags with treatment or time. Thinning treatments had no effect on snag densities in any size or mortality class. Few new snags were created by the thinning operation, and thinning led to insignificant declines in old and total (new + old) snag abundance in all diameter classes. Thinning led to small but significant increases in QMD (Quadratic Mean Diameter; the diameter of the tree of average basal area in the stand) of old snags whereas QMD on unthinned units tended to decline after fire treatments. In both models, analysis indicated that thinning led to a reduction after accounting for pretreatment variation in snag QMD. Thinning alone was the only treatment that consistently reduced snag populations, created few new snags, and had no effect on bark beetle attack incidence. Post-treatment snag density in these units was among the lowest recorded across all treatment units and in all size classes. Because snag retention was not the primary focus of this treatment, snags were often removed because of the safety hazard that exists with operation of mechanized equipment. The unbalanced experimental design precluded analyses of individual treatment effects and probably the finding of significant reductions in snags on thin-only units. The spatial distribution of snags is important for certain wildlife species. For example, the Lewis's woodpecker, listed as a sensitive species by the US Forest Service, prefers snags >20 cm dbh arranged in small clumps on the landscape, rather than areas with uniformly or randomly dispersed snags. The thin-only treatment reduced clumpiness, leading to a more random snag distribution, whereas the burn-only and thin-burn treatments generally retained or enhanced a clumped snag distribution. Bark beetles attacked ~75% of snags across all units before and after treatments, and red turpentine beetle occurrence tended to increase after prescribed burning.

Hessburg, Povak and Salter (2010) state that these considerations have important implications for future silvicultural prescriptions and snag management. By directly influencing the spatial patterns of surface fuels and fuel concentrations, managers may protect existing large snags and recruit new large snags to the landscape. Their findings can be used to tune silvicultural prescriptions to meet stocking, spacing, and fuel reduction objectives while retaining or recruiting snags, thereby increasing the utility of conditions for certain wildlife species.

Some recent studies that address how particular genera and species of wildlife respond to fuels treatments are summarized below. Comparing conclusions among these studies will reinforce the point that from a wildlife perspective, identification of focal species, or species of special concern in a particular fuels project area is a critical first step that can strongly influence the type and location of treatments. As Lemkuhl and others (2007) put it, "some species will gain and some species will lose habitat when stand structure or composition is changed during fuel

reduction treatments.” (P. 73.) For example, Stephens and Alexander (2010) argue that although unthinned buffers along streams are the norm for fuels treatment prescriptions, thinning in these areas could benefit bird populations by reducing wildfire risk and the chance that these habitats will be impacted by uncharacteristically severe fires. Conversely, Bury (2004) points out that most riparian amphibians require cool, moist environments associated with high canopy cover, and argues that maintaining adequate unthinned streamside buffers is critical for these animals.

Birds

Verschuyf and others (2011) summarized documented relationships between forest thinning treatments and forest biodiversity in a synthesis document that combined a meta-analysis of 505 biodiversity effect sizes from 33 studies conducted across North America with qualitative discussion of other studies that did not meet the criteria for inclusion in the meta-analysis. Thinning intensity played a significant role in bird response. Birds responded favorably to light and moderate thinning, but heavy thinning led to the only significantly negative responses for both taxa/guild abundance and the cumulative effect measure for birds. Compared to other thinning treatments, fuels treatment thinning resulted in the largest effect sizes for birds suggesting a strong positive response for avian species diversity and abundance. The authors speculate that re-generation of the forest shrub layer may account for this in many cases. Verschuyf and others (2011) caution that while their results suggest that bird diversity may often increase with thinning, consideration needs to be given to species of high conservation priority that may be negatively affected, either directly or indirectly, by thinning.

Stephens and Alexander (2010) investigated the effects of fuels reduction on bird communities in riparian areas in southwestern Oregon. The authors note that although studies in this area suggest that riparian areas within mixed-conifer forests historically burned with frequencies and intensities similar to upland areas, riparian areas are typically excluded from fuels treatments because human disturbances are perceived to negatively affect these areas. The study compared the effects of non-commercial thin and handpile treatments followed by prescribed burns in riparian areas of intermittent and perennial streams that were treated to the streamside (unbuffered), to the typical prescription in which sites were treated only in the adjacent upland (buffered). The study assessed whether unbuffered fuel reduction treatments yielded similar bird response as buffered treatments by quantifying differences in density and reproductive success of five “focal” bird species, vegetation structure, the frequency of occurrence of predators and a nest parasites, and arthropod biomass. Density was greater for the shrub and tree-nesting Pacific-slope flycatcher in buffered streams post treatment. Reproductive success in unbuffered streams was slightly reduced in the near-term for the shrub-nesting black-headed grosbeak, but reproductive success was stable or increased in both buffered and unbuffered streams after completion of all treatments.

Stephens and Alexander (2010) hypothesize that post-handpile retention of shrubs in the riparian area of the buffered stream was correlated with greater reproductive success of black-headed grosbeaks, because of their affinity to riparian nest sites in dry forests. Although treatment prescriptions called for retention of all riparian shrub species, the authors noticed

replacement of low growing riparian shrubs with herbaceous vegetation after treatments in unbuffered streams. Treatments were completed primarily during winter, so shrubs were difficult to identify without foliage. Future fuels treatments in riparian areas should either occur during times when shrubs are leafed out, or shrubs should be flagged, to assure their retention. Overall, results suggest that fuel reduction in riparian areas as compared with typical upland treatments with buffers had a small effect on bird density and a near term effect on reproductive success. The authors qualify their results by noting that sample sizes were relatively small and note that the riparian areas within this study, as is typical of dry mixed-conifer/broadleaf forests, are narrow and in many cases similar to uplands in vegetation structure and composition. Thus, it is likely that the effect of a buffer on density and reproductive success for some species would be washed out by the effect of treatment in upland areas. Additional study of fuel reduction in riparian areas is warranted because of its effectiveness in reducing the risk of unnaturally severe wildfire and, correspondingly, the potential benefit to bird communities over the long-term.

Seavy and others (2008) compared bird abundance and vegetation structure at four untreated stands and four stands where shrub cover had been reduced by using mechanical mastication thinning in SW Oregon oak woodlands and chaparral. In a previous study (Alexander et al. 2007), the researchers compared bird abundance in areas where shrub cover had been reduced by hand on relatively small plots (7–42 ha) and untreated areas. In that study, six bird species were more abundant on the treated plots, species mostly associated with open conditions or forest edges. Surprisingly, there was little evidence that species associated with shrubs were less abundant in the treated areas. The researchers surmised that these species' ability to persist in treated areas was facilitated by the small size of the treatment areas and the maintenance of untreated areas within treatment stands (0.4– 1.2 ha). In the more recent study, larger-scale shrub removal treatments using heavy equipment were assessed. Seavy and others (2008) hypothesized that because these treatments are larger and leave a smaller proportion of the area untreated, the effects on shrub associated birds would be greater.

To test this hypothesis, they compared vegetation structure and bird abundance over a 2-year period in treated and untreated stands. Three bird species were consistently more abundant on untreated stands. Species that were more abundant on untreated stands were associated with shrub cover, while those that tended to be more abundant on treated stands were associated with open areas, providing further evidence that the treatments were responsible for observed differences in bird community composition. This stronger response of shrub-associated species than was documented in the researchers' earlier study of smaller-scale treatments (Alexander et al. 2007) suggests that managers can design treatment prescriptions that benefit particular species by altering the size and shape of treated areas as well as the tools that are used to reduce shrub cover (e.g., mechanical vs. manual treatments).

Seavy and others (2008) offer some suggestions to managers designing treatment prescriptions in oak woodland and chaparral vegetation types of southern Oregon. First, small scale treatments are likely to have less impact on shrub-associated species, such as Bewick's wren, wrentit, and possibly the California towhee. They propose that small treatments designed to

maintain shrub-associated bird species should be <50 ha, and large treatments designed to benefit open-habitat species should be >100 ha but emphasize that these preliminary guidelines should be used with caution and potentially adjusted based on monitoring. Also, enhancing habitat for edge-associated species may be better accomplished with small-scale treatments than with large-scale treatments because small-scale treatments produce more edge for a given treatment area.

Lyons and others (2008) examined short-term responses of cavity-nesting birds in dry conifer forests of Washington to fuel reduction treatments. Their objective was to determine if altering the forest stand through mechanical thinning or prescribed burning or a combination of the two would alter foraging tree selection. Much information exists on nesting requirements of cavity-nesters, while little information is available on their foraging requirements, or how changes to their habitat affect foraging. We modeled foraging tree selection and analyzed the effects of treatments on foraging tree selection.

Results suggested that cavity-nesting birds (chickadees, nuthatches and woodpeckers) selected for large diameter trees and fuels treatments had a positive impact on foraging for nuthatches and woodpeckers. Birds were more likely to be observed foraging in treated stands and the positive relationship was strongest in stands that received a combination of thinning and burning treatments. Nuthatches and woodpeckers were more likely to be observed foraging in treated stands, while tree diameter was far more influential on chickadees regardless of treatment. Enhanced foraging conditions in the thin–burn treatment may have resulted from more complete removal of small trees- the prescribed burn was so low-intensity, it did not remove many small trees. Bird groups selected for trees at least 1.6 times as large in diameter in treated stands as compared to control stands. Results indicate that thinning and burning may best enhance foraging habitat for bark gleaning species as a whole. Based on these results, some important treatment design considerations include removal of small trees and retention of large trees and snags (>40 cm dbh) that provide important foraging substrate and nesting habitat.

Hurteau and others (2010) evaluated how several currently used fuel reduction treatments (e.g., mechanical thinning and prescribed fire alone and in combination) affect nest attributes, nest density, nest tree occupancy, and home range size of Western Bluebirds in ponderosa pine dominated forests of northern Arizona. Nest attributes, such as number of eggs or nestlings, varied among treatments, but did not differ statistically. Western Bluebird nest density was significantly higher in treated areas, even though snag density was lower in treated areas than in control areas. The authors conclude that increased nest occurrence in treated sites is probably due to the loss of snags in the burned units and the subsequent use of the remaining snags by an increased number of birds.

Home range estimates were calculated for 28 breeding male Western Bluebirds tracked using radio telemetry. The average area of the 50% contour, across all treatment units, was 0.42 +/- 0.07 ha, and the average area of the 90% contour was 2.36 +/- 0.30 ha. Home range sizes for both probability contours evaluated were 1.5 times larger in the thin-only treatments than in

the control units. Conversely, home range area in thin-and-burn treatments was approximately 30% smaller than in control units. The largest home ranges occurred in the burn-only treatments. The results of Hurteau and others (2010) suggest that thinning and prescribed fire are generally beneficial to Western Bluebirds, but that low snag retention may be a problem in areas receiving prescribed fire as part of their treatment.

Mammals

Verschuyf and others (2011) summarized documented relationships between forest thinning treatments and forest biodiversity in a synthesis that combined a meta-analysis of studies conducted across North America with qualitative discussion of other studies that did not meet the criteria for inclusion in the meta-analysis. Measured effects came primarily from studies of small mammals but also included large herbivores. (No studies of large carnivores were included.) The deer mouse was the most frequently reported individual species. The number of effect size measures of mammalian taxa/guild abundance and diversity were somewhat limited, thus limiting conclusions based on the meta-analysis. Nonetheless, mammalian diversity and abundance were higher in thinned stands than unthinned controls across most regions, but magnitude of the mammalian response to thinning treatments varied significantly between regions. Most studies were in the Northwest region (72%), where there was no significant mammalian species abundance or diversity response to thinning treatments. The authors note that although commercial thinning resulting in open canopies and increased understory growth may favor measures of mammalian species abundance or diversity, it may not improve habitat conditions for species associated with closed-canopy conditions. However, intermediate or variable density treatments may produce habitat for generalists and closed canopy or arboreal specialists. Despite the generally positive response by mammals to forest thinning, some direct and indirect effects of forest thinning on species of conservation concern may warrant further review (e.g., northern flying squirrel habitat connectivity and food resources [Carey 2000; Gomez et al. 2005] and snowshoe hare/Canada lynx population dynamics.)

Noting that despite its importance for wildlife, most Pacific Northwest forests contain low volumes of large downed wood compared to fine woody debris (FWD). Manning and Edge (2008) used a replicated experiment to compare short-term responses of deer mice and western red-backed voles among 3 arrangements of FWD: piled, lopped and scattered, and pile burning, a commonly used method of fuel reduction in commercial Douglas fir forests in southwest Oregon, USA. The researchers assessed habitat use, density, and survival of mice and voles during 2 consecutive summers. Both mice and voles used FWD cover disproportionately from its availability, and they differed in their responses to specific FWD arrangements. Mice used piled FWD 43% more than expected. Number of mice captured at individual FWD piles decreased up to 16% and index of home range size increased up to 50% for each 1-m increase in distance from piles. Voles used all FWD cover classes in proportion to availability, but number of voles captured increased slightly for each 1-m increase in distance from piles. Piled FWD had no discernable effect on population density and apparent survival of mice, but analyses had low power. The results of Manning and Edge (2008) suggest that piling FWD would benefit deer mice, whereas lopped and scattered FWD might benefit voles. Pile

burning alone may not provide habitat conditions that are necessary to support the entire community of small mammal species. Thus, a combination of methods to reduce fire risk should be considered to accommodate multiple small mammal species. The authors note that small mammals are important prey for sensitive species such as the pygmy owl and spotted owl. These results also suggest that the needs of small mammal species should be considered before implementing projects that remove forest biomass from the forest.

Long, Rachlow and Kie (2008) evaluated effects of season and spatial scale on response of Rocky Mountain elk and mule deer to experimental habitat manipulation at the Starkey Experimental Forest and Range in northeastern Oregon. From 2001 to 2003, 26 densely stocked stands of true fir and Douglas-fir were thinned and burned whereas 27 similar stands were left untreated as controls. The researchers used location data for elk and mule deer collected during spring and summer of 1999–2006 to compare use of treated and untreated stands and to model effects of environmental covariates on use of treated stands.

In spring, elk selected burned stands and avoided control stands in the study area. Within home ranges however, elk did not exhibit selection. In addition, selection of treatment stands by elk in spring was not strongly related to environmental covariates. Conversely, in summer elk selected control stands and either avoided or used burned stands proportional to their availability at the large scale; patterns of space use within home ranges were similar to those observed in spring. This effect may have resulted from both seasonal changes in phenology of forage species and presence of cattle at Starkey during summer. Average temperatures at Starkey are substantially higher in summer than in spring. In areas with relatively open canopy cover most grass species and many forbs have cured or senesced by mid-July from exposure to direct sunlight. Conversely, in areas with denser canopy cover those species often persist for several weeks longer, so control stands might actually provide better foraging opportunities than burned stands during hotter summer months. Use of treatment stands by elk in summer was related to topography, proximity to roads, stand size and shape, and presence of cattle. Patterns of stand use by mule deer did not change following habitat manipulation. Mule deer avoided or used all stand types proportional to their availability across seasons and scales.

Long, Rachlow and Kie (2008) conclude that In systems similar to Starkey, manipulating forest habitat with prescribed fire might be of greater benefit to elk than mule deer where these species are sympatric, and thus maintaining a mixture of burned and unburned (late successional) habitat might provide better long-term foraging opportunities for both species than would burning a large proportion of a landscape. Long, Rachlow and Kie (2008) did not analyze a “thinning only” treatment.

Reptiles and amphibians

Verschuyf and others (2011) note that many reptile populations are potentially in decline but that research documenting response of reptiles to timber harvest is limited. Solar radiation and thermal cover are important habitat characteristics for reptiles. Clearcutting provides ample solar radiation for morning sunning, but may not provide adequate night time thermal cover in some regions. However, thinning may provide more moderate environments for reptile species

than closed-canopy or recently clearcut stands. Many lizard species, some of which have been reported in decline, have been shown to be more abundant in recently harvested stands. Available research (primarily from the southeastern U.S.) suggests that the effects of forest harvest on reptile species varies depending on their life histories. Verschuyf and others (2011) indicated that there is insufficient research to draw conclusions about response to different thinning intensities and regional differences in reptile response to various thinning treatments.

The meta-analysis from Verschuyf and others (2011) included 19 amphibian responses from 5 studies; 2 in the northwestern U.S. (Garman 2001; Suzuki 2001), and 3 in the southeastern U.S. Most responses of amphibians to thinning were negative. The cumulative effect size (response ratio) for all abundance and diversity measures was 0.94, but was not significantly different from 1.00. However, the cumulative taxa/guild abundance effect size (0.95) was significantly less than 1. (Response ratios < 1.00 indicate a negative response to forest thinning; ratios > 1.00 indicate a positive response.) Suzuki (2001) and Matthews and others (2010) reported lower total amphibian abundance in thinned stands than unthinned stands. Twelve of 19 reported effects were negative. Salamanders represented 11 of 19 effect sizes used to summarize amphibian response to thinning.

Verschuyf and others (2011) discuss other scientific evidence regarding amphibian response to thinning not included in their meta-analysis. Salamanders, particularly plethodontid salamanders, are often more abundant in closed canopy forests and later successional stages. Declines of up to 80% for some salamanders and species richness declines of up to 50% have been reported following even-age timber harvest in some forest types (Petranka and others 1993). In a comprehensive review of amphibian response to forest management in North America, deMaynadier and Hunter (1995) report the short-term, stand-level response of salamanders to timber harvest is typically negative, usually due to reduced leaf litter, canopy cover and soil moisture. Pough and others (1987) showed a strong relationship of understory vegetation and leaf litter depth with above-ground salamander activity, and Ash (1997) reports the timing of amphibian return to previously harvested stands closely follows re-development of the litter layer. These findings suggest that biomass harvesting practices which preserve the forest litter layer may reduce the potential for impacts on amphibians.

Verschuyf and others (2011) found less information on amphibian response to partial harvest or thinning. Some suggest that detrimental effects of stand disturbance (e.g., soil compaction, stream sedimentation) on amphibian populations persist even when the disturbance is a less severe partial cut (Harpole and Haas 1999; Semlitsch and others 2009). Several studies report mixed or even positive effects of thinning on amphibian populations (e.g., Pough and others 1987; Grialou and others 2000) suggesting that some thinning prescriptions can maintain forest amphibian populations.

Bury (2004) discusses the influences of wildfire, forest management and fuels reduction on reptile and amphibian habitat in western forests, with a primary focus on the Klamath-Siskiyou region of southern Oregon and northern California. Bury (2004) notes that many amphibian species have declined across the west and are thus of particular conservation importance.

Most amphibians require cool, moist environments associated with denser, older forests that have much downed wood and cool, cascading streams. Large pieces of downed wood and the moist, thermally stable habitat they provide are also critical for terrestrial amphibians. When habitat conditions are altered, stream amphibians are very slow to recover, sometimes not returning to pre-harvest levels for many decades. Bury (2004) recommends that for any fuels reduction project, special attention should be given to stream-dwelling amphibians which are particularly vulnerable to changes in thermal and sediment conditions that may result from thinning in riparian areas. Adequate stream buffers are especially important for these species.

Bury (2004) suggests that to reduce the likelihood of stakeholder challenges to active forest management projects (such as forest biomass removal) managers should better evaluate the habitat requirements of amphibians. Key habitats - seeps, headwater streams, riparian zones, and talus slopes in mature forests - are patchily distributed on the landscape, but their protection or restoration would ensure the conservation of a large proportion of native amphibians.

The opening of closed forest canopies or dense shrub by thinning would likely benefit most species of reptiles, which generally prefer warm, dry upland areas or slopes. Such alterations of habitat may be particularly important to species such as striped racers and whiptail lizards that require open, dry terrain. Most reptiles prefer grassland, chaparral, oak woodlands, or open forest.

Greenberg and Waldrup (2008) studied the response of reptiles and amphibians to three fuel reduction techniques in a southern Appalachian upland hardwood forest composed mainly of oaks and hickories, with some shortleaf and Virginia pines on ridgetops, and white pine in moist coves. Forest age on the study sites was 80-120 years, with elevations from 1600'-2100'. Predominant shrubs were mountain laurel along ridge tops and on upper southwest-facing slopes, and rhododendron in mesic areas. None of the sites had been thinned or burned for at least 50 years. Treatments were prescribed burn (B); mechanical understory reduction (M); mechanical + burn (MB); and controls (C).

Greenberg and Waldrup (2008) note that most prescribed fire in eastern hardwood forest does not eliminate canopy cover, coarse woody debris or duff, which provide important habitat components for terrestrial amphibians cover by ameliorating temperature fluctuations and moisture levels on the forest floor. Several studies in this ecosystem suggest that heavy canopy removal (e.g., clearcuts, shelterwood cuts) can adversely affect local amphibian populations, especially salamanders. Conversely, lizards and other reptiles may increase as a result of higher light levels, warmer, drier microclimates and reduced leaf litter cover, changes that are not favorable to salamanders but facilitate movement and thermoregulation for many reptile species.

For mechanical treatments, the understory was reduced using chainsaws and included all mountain laurel, rhododendron, and other shrubs and trees >1.8 m tall and <10.0 cm in diameter at breast height (dbh). Cut fuels were left scattered onsite so that low or no piles

remained. The objective of all treatments was to reduce ladder fuels by substantially reducing the shrub layer. Fire intensities for the prescribed burns varied within and among sites, but were generally moderate to high. Hot fires in MB treatment killed approximately 25% of the trees within a few months of the burns. Leaf litter depth was significantly lower (reduced by >80%) in both burned treatments (B and MB) after burning, but increased in M due to the addition of dead leaves during understory felling. None of the treatments had an immediate effect on duff depth or percent cover of coarse woody debris.

Over the 4-year study period, 13 species of reptiles and 13 species of amphibians were captured. Mechanical understory reductions did not have a detectable effect on the relative abundance or species richness of total amphibians or reptiles, or on the relative abundance of total frogs and toads, salamanders, lizards, or snakes when these groups were broken out for analysis. Mechanical understory reductions did not have a detectable effect on the relative abundance of any tested species except green frogs, which decreased.

Salamanders and newts showed little numerical response to any of the fuel reduction treatments. Greenberg and Waldrup (2008) note that this was somewhat surprising, as several micro- and macro-habitat conditions that mediate moisture and temperature at ground level, including leaf litter depth, live tree density, and canopy cover were dramatically reduced in MB (as was leaf litter depth in B). However, duff depth and percent cover of coarse woody debris did not differ among the treatments and may have provided sufficient cover and moisture for woodland salamanders. Further, salamanders may retreat underground and emerge at night to forage on the forest floor when temperatures are cooler and moisture levels are higher. Total reptiles and fence lizards were more abundant in MB than in B.

Greenberg and Waldrup (2008) explain that low treatment replication ($n = 3$ per treatment and control) and relatively low capture rates increased the likelihood that they did not detect some responses that did indeed occur. They also note that some response patterns can be difficult to interpret with limited replication, particularly for aquatic-breeding amphibians where proximity to breeding sites exerts a strong confounding influence. Greenberg and Waldrup (2008) nonetheless believe that their results for salamanders (no response) and reptiles (tendency to be higher in MB) reflect real trends, and their findings are corroborated by other studies in eastern hardwood forest.

Overall, Greenberg and Waldrup's (2008) results indicate that a single application of the fuel reduction methods studied will not negatively affect amphibian or reptile abundance or diversity in the eastern hardwood ecosystem where their study was conducted. Results further suggest that high-intensity burning with heavy tree-kill, as in MB, can be used as a management tool to increase reptile abundance – particularly lizards – with no negative impact on amphibians, at least in the short-term. Kennedy and Fontaine (2009) also summarize Greenberg and Waldrup (2008) but caution that "...the scope of inference of this study is quite limited due to use of abundances and count indices unadjusted for capture probabilities—a major problem with taxa that are difficult to detect, such as amphibians and reptiles. Thus,

extension of [these] results to other sites or forest types should be done cautiously and in an experimental manner permitting rigorous evaluation and testing of hypotheses.” (P. 54.)

In a longer-term study at the same Appalachian Mountain site utilized by Greenberg and Waldrup (2008) Matthews and others (2010) captured reptiles and amphibians in a control and 3 replicated fuel-reduction treatments: 1) twice-burned (2003 and 2006), 2) mechanical understory cut (2002), and 3) mechanical understory cut (2002) followed by 2 burns (2003 and 2006). The researchers captured fewer salamanders in mechanical + twice-burned treatment areas than in twice-burned and control treatment areas, but more lizards in mechanical + twice-burned treatment areas than in other treatment areas. Higher lizard captures in mechanical + twice-burned treatment areas likely was related to increased ground temperatures and greater thermoregulatory opportunities. Higher and more variable ground temperatures and faster drying of remaining litter and duff may have led to fewer salamander captures in mechanical + twice-burned treatment areas. Longer term results, after 2 prescribed burns, differed from shorter term results. After one prescribed burn at the same site, eastern fence lizard captures were greater in mechanical + burn treatment areas but salamander captures did not differ among treatment areas.

Results indicated that the mechanical + twice-burned treatment benefited lizards but adversely affected salamanders. Reptiles and amphibians showed little response to other fuel-reduction treatments. These responses were likely due to a combination of reduced litter and duff depth and a more open canopy in mechanical + twice-burned treatment areas, resulting from hot fires and substantial overstory mortality. Average maximum fire temperatures in the second prescribed burn were higher in the mechanical + twice burned treatments (222⁰ C) than in the twice-burned treatments (155⁰ C). Salamander captures in twice-burned treatment areas were not different from those in control treatment areas, indicating that less intense fires did not affect salamander populations. Similarly, salamander captures in mechanical treatment areas that did not disturb the canopy were not different than captures in other treatment areas.

Matthews and others (2010) conclude that fuel reduction by mechanical understory cutting or multiple, low-intensity prescribed fires have little effect on reptile or amphibian communities of southern Appalachian Mountain hardwood forests, but mechanical understory reduction coupled with high-intensity, multiple burns may decrease salamander abundance and increase lizard abundance. Findings that salamanders are negatively affected in mechanical + twice-burned treatment areas contrast with Greenberg and Waldrup (2008) results at the same study site after one burn, suggesting that effects of multiple treatments may be additive or that the population response to initial treatments may take longer to manifest than has been addressed in prior studies. These results combined with those from Greenberg and Waldrup (2008) emphasize the need for long-term studies to assess reptile and amphibian responses to fuel-reduction treatments after multiple burns.

Invertebrates

Verschuyf and others (2011) found 46 invertebrate responses (effect sizes) from 2 studies; 1 in the northwestern U.S. (Yi 2007), and another in the upper Midwestern U.S. (Tibbels and Kurta

2003). In thinned stands there was significantly higher biomass of invertebrates than in unthinned stands for 35 of 42 order biomass effect sizes. The cumulative effect size (response ratio) of 1.10 for 42 order biomass measures and 4 measures of order diversity was significantly greater than 1.00. (Response ratios < 1.00 indicate a negative response to forest thinning; ratios > 1.00 indicate a positive response.) Depending on their life history characteristics, invertebrate communities may respond positively, negatively or minimally to forest thinning. The research Verschuyf and others (2011) summarized, including responses for herbivore, predator, and detritivore arthropods, showed a significant positive response to forest thinning treatments. However, these results are limited in geographic scope and in the number of included studies (3).

6. Effects of woody biomass collection and conversion on plant resources

Key findings for plant diversity:

- a. The response of plant species diversity to forest thinning across most Oregon ecosystems is likely to be positive, but will depend on forest type, treatment type and treatment intensity.
- b. Depending on the site, a significant portion of increased plant species diversity resulting from thinning may be in the form of invasive exotic species. Managers should survey for exotic invasives that may be present prior to any thinning activities and take steps to mitigate their spread after thinning.

Verschuyf and others (2011) summarized documented relationships between forest thinning treatments and forest biodiversity in a synthesis that combined a meta-analysis of studies conducted across North America with qualitative discussion of other studies that did not meet the criteria for inclusion in the meta-analysis. The focus of Verschuyf and others' (2011) synthesis was almost exclusively on animals, but they do include a short discussion of studies on the effects of forest thinning on plant diversity, which is paraphrased below.

The response of plant species diversity to forest thinning is often positive, but has been examined less frequently than animal species diversity. In the northwestern U.S. and Canada, species richness of understory vegetation in thinned stands was similar to (Deal 2001) or greater than (Thomas and others 1999) uncut control stands. In structurally complex temperate rain forests of the northwestern U.S., thinning increased growth of important mid-canopy layers (Comfort and others 2010). Lodgepole pine forests of the Northwest Interior exhibited few differences in plant species diversity or composition between thinned and unthinned stands (Sullivan and others 2002). Plant species richness in ponderosa pine forests of the southwestern U.S. was least in unmanaged stands and increased with greater thinning intensity (Griffis and others 2001). However, exotic species were a large part of the increase in richness for harvested stands, and number of native shrub species decreased significantly with treatment intensity (Griffis and others 2001). In Sierran mixed conifer forests, canopy closure, used as a measure of thinning intensity, was shown to be negatively related to plant species richness (Battles et al., 2001). In addition, plant species composition varied significantly with

intensity of thinning treatments. High intensity treatments maximized species richness but understory vegetation typical of late seral stands was more abundant in lightly thinned or control stands. Furthermore, control stands had lower proportions of exotic species (Battles et al., 2001). By 3 years post-treatment, thinned stands showed significantly higher plant species richness than control stands in the Piedmont of South Carolina (Phillips and Waldrop, 2008). In summary, the response of plant species diversity to forest thinning across much of North America is likely to be positive, but will depend on the forest type and treatment intensity. Plant species composition and abundance of exotic species are also likely to vary with thinning intensity.

For a more in-depth discussion of the effects of thinning on non-tree vegetation, see Kerns and others (2003) and the summary based on this reference in the “Effects of woody biomass collection and conversion on plant resources” section of the 2008 report (Oregon Department of Forestry 2008).

7. Effects of woody biomass collection and conversion on water quality

Key findings for water quality:

- a. The effects of various forest harvesting and thinning regimes on water quality have been extensively researched and are addressed in existing forest practice guidance for many states, including Oregon. Best forest management practices for water quality also apply to removal of forest biomass.
- b. Some states are reviewing their current forest practice guidance to ensure that it fully accounts for potential differences in effects between forest biomass removal activities and conventional timber harvesting.

The effects of active forest management on water quality have been the focus of a substantial amount of research over several decades covering a range of silvicultural options and different types of forest ecosystems. Oregon’s forest practice guidance contains many provisions for mitigating impacts on water quality. In general, these guidelines are also applicable to forest biomass removal.

After a comprehensive review of the potential ecological risks associated with biomass harvesting and a review of Maryland’s existing forest management programs, the Pinchot Institute for Conservation and the Maryland Department of Natural Resources completed a *Guide to Forest Biomass Harvesting and Retention in Maryland* (Pinchot Institute for Conservation and the Maryland Department of Natural Resources 2010).

The authors noted that many of the recommended practices contained in the guide are standard forest management operations in Maryland, but that other practices contained in the guide may be new. They also noted that while forest biomass removal in Maryland would likely accompany conventional timber harvests and thus be subject to regulatory and non-regulatory programs already active in Maryland, “...the removal of additional woody material is not wholly

addressed by existing forest management programs, and biomass harvests may negatively impact forest health and productivity if precautions are not taken.” (Pinchot Institute for Conservation and the Maryland Department of Natural Resources 2010, p. 1.)

With regard to water resources, the guide states that “If implemented through a well-planned harvest, existing water quality Best Management Practices (BMPs), approved in Maryland’s Erosion and Sediment Control Plan, should protect water quality during timber and biomass harvests. Still, ensuring that sufficient coarse woody debris (CWD) remains following harvest can help maintain water quality by inhibiting potential runoff. Deadwood improves water quality and serves as an essential habitat feature in both terrestrial and aquatic landscapes, and thus it is important to maintain preexisting CWD and snags in riparian areas (areas adjacent to streams) and in wetlands.” (Pinchot Institute for Conservation and the Maryland Department of Natural Resources 2010, p. 12.)

The guide then lists Best Management Practices (BMP) for protecting water quality during removal of forest biomass. In addition to direction to follow existing Maryland regulations regarding erosion control the guide states that:

- The removal of tops and limbs in an amount that is greater than what would normally be removed under regular timber harvests should be avoided in riparian buffers when performing a harvest under a buffer management plan (part of a custom plan attached to a standard sediment and erosion control plan).
- Avoid biomass harvesting in highly erosion-prone sites (e.g., sites with slopes greater than 40% and sites with exposed soil) and take care to leave appropriate amounts of limbs and tops on the ground, especially in sites with slopes greater than 20%.
- If fertilizing, consult appropriate resources (e.g., Maryland extension publications on fertilization of plantation forests and regional extension agents focused on forestry) with regard to appropriate fertilization techniques.

(Pinchot Institute for Conservation and the Maryland Department of Natural Resources 2010, p. 13.)

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Title/Authors/ Journal/Source	Date	Description/Type/ Scope/Location	Resources/ Species	Peer review	Comments on Document, Abstract, Notable Findings
Reinhardt, E.D., R. E. Keane, D.E. Calkin, J.D. Cohen. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States Forest Ecology and Management 256, pp 1997–2006.	2008	Detailed overview of purposes and limitations of fuels reduction	Wildfire, prescribed fire	Yes	Abstract: Many natural resource agencies and organizations recognize the importance of fuel treatments as tools for reducing fire hazards and restoring ecosystems. However, there continues to be confusion and misconception about fuel treatments and their implementation and effects in fire-prone landscapes across the United States. This paper (1) summarizes objectives, methods, and expected outcomes of fuel treatments in forests of the Interior West, (2) highlights common misunderstandings and areas of disagreement, and (3) synthesizes relevant literature to establish a common ground for future discussion and planning. It is important to understand the strengths and limitations of fuel treatments to evaluate their potential to achieve an objective, develop sensible fire management policies, and plan for their effective use. We suggest that, while the potential of fuel treatment to reduce wildfire occurrence or enhance suppression capability is uncertain, it has an important role in mitigating negative wildfire effects, increasing ecosystem resilience and making wildfire more acceptable.
WILDLIFE - GENERAL					
Synthesis of Knowledge on the Effects of Fire and Fire Surrogates on Wildlife in U.S. Dry Forests Special Report 1096. Sept. 2009. Kennedy. P.L., and J.B. Fontaine. Extension and Experiment Station Communications Oregon State University, Corvallis. http://extension.oregonstate.edu/	2009	Synthesis of existing knowledge on wildlife responses to fire and fire-surrogate treatments. Dry forests of continental U.S. grouped into 6 regions: pine east, pine west, interior mixed-conifer, Pacific mixed-conifer, eastern hardwood, Great Lakes.		Yes	Includes species-level summary tables to help project biologists and fire managers anticipate effects of fire and fire-surrogate treatments on local wildlife species. Based on survey of published, peer-reviewed scientific literature on wildlife response to fire and fire-surrogate treatments. Review of 90 articles, resulted in 4,937 records of 313 vertebrate species. Primarily focused on fire effects. Report does summarize some studies that included thinning only (i.e. without fire) as a treatment, but no general summary of thinning or biomass removal effects is included. One key point is that when results from similar studies in different geographic areas are compared, “in many cases, the site effect overwhelmed any effect of treatment. This is likely caused by the extreme heterogeneity in pretreatment site conditions, which influenced the post-treatment site conditions. The ability to identify consistent treatment effects in the FFS studies is also hindered by a lack of understanding of the treatments’ effect on local habitat features that influence local wildlife demography.”
Seeing the forest for the fuel: Integrating ecological values and fuels management Lehmkuhl, J.F. M. Kennedy, E.D. Ford, P.H. Singleton, W.L. Gaines, R.L. Lind. Forest	2007	PNW	Uses northern spotted owl, as an example. Model is applicable to any species or	Yes	Abstract: Management of dry forests often involves trade-offs between ecological values, particularly those associated with closed-canopy forests, and reduction of severe wildlife risk. We review principles and our ecological research that can be used to design stand- and landscape-level fuel treatments in dry coniferous forests of western North America. The focus of ecological values is on the ecological web that includes the

Title/Authors/ Journal/Source	Date	Description/Type/ Scope/Location	Resources/ Species	Peer review	Comments on Document, Abstract, Notable Findings
Ecology and Management 246 (2007) 73–80.			resource that can be mapped		northern spotted owl (<i>Strix occidentalis caurina</i>), its two primary prey species the northern flying squirrel (<i>Glaucomys sabrinus</i>) and bushy-tailed woodrat (<i>Neotoma cinerea</i>), and the vegetation (live and dead), mycorrhizal fungi, and arboreal lichens that support those prey species. For the landscape level, we describe an ongoing project to develop the FuelSolve computer tool that optimizes the area and location of a fuel treatment by minimizing potential fire behavior and minimizing loss of spotted owl habitat from treatment and potential fire. Some species will gain and some species will lose habitat when stand structure or composition is changed during fuel reduction treatments. Stand-level prescriptions might be altered to maintain or create patchiness of closed-canopy habitat elements, such as snags, down wood, mistletoe-infected trees, and large old trees, and open-canopy habitats can be tailored to ensure creation of suitable composition and structure for wildlife. Allocation of treatments across the landscape might be managed to minimize cumulative effects and impacts on target species populations. General approaches to landscape-level planning of ecologically sound fuel treatments include coarse- and fine-filter approaches. A coarse-filter approach would use some definition of the historical or natural range of variability to define the composition and pattern that might reasonably be expected to sustain the forest ecosystem. Three general approaches can inform fine-filter analysis and development of fuel reduction treatments at the landscape level. Population viability analysis provides sound principles based on attributes of the species population structure, life history and behavior, and environment (habitat) for guiding fine-filter analysis. Fine-filter analysis can be informed by operational modeling of treatment alternatives. Research publications can guide dry forest landscape management. Our FuelSolve optimization model described in this paper differs from other fuel planning models in this class by equally considering multiple optimization objectives for fuel treatment and ecologically important resources. We describe the results of FuelSolve prototype development, an evaluation of outputs for field use, and future development efforts.
Hessburg, P.F., N.A. Povak and R. B. Salter. 2010 Thinning and Prescribed Fire Effects on Snag Abundance and Spatial Pattern in an Eastern Cascade Range Dry Forest, Washington, USA	2010	Central Washington State	Snags	Yes	Mechanical thinning and prescribed burning practices are commonly used to address tree stocking, spacing, composition, and canopy and surface fuel conditions in western US mixed conifer forests. We examined the effects of these fuel treatments alone and combined on snag abundance and spatial pattern across 12 10-ha treatment units in central Washington State. A snag census was conducted before and immediately after treatments on each unit where all snags were

Title/Authors/ Journal/Source	Date	Description/Type/ Scope/Location	Resources/ Species	Peer review	Comments on Document, Abstract, Notable Findings
Forest Science 56(1)					measured and classified as either “new” (1 year as a snag) or “old” (1 year as a snag) mortality, and bark beetle species were censused on the bottom 3-m of the bole. Before treatment, snags were found in all units and more than two-thirds of the snags were ponderosa pine. Burning (burn-only and thin-burn combined) treatments led to increases in total snag abundance in all but the largest diameter class. Snag abundance in the large snag class (60 cm dbh) decreased in most treatment units indicating that units with high abundance before treatment had the potential to lose more snags with treatment or time. Treatments also affected the spatial distribution of snags. The thin only treatment reduced clumpiness, leading to a more random snag distribution, whereas the burn-only and thin-burn treatments generally retained or enhanced a clumped snag distribution. Bark beetles attacked 75% of snags across all units before and after treatments, and red turpentine beetle occurrence tended to increase after prescribed burning. Managers can use this information to tune silvicultural prescriptions to meet stocking, spacing, and fuel reduction objectives while retaining or recruiting snags, thereby increasing the utility of conditions for certain wildlife species.
Biodiversity response to intensive biomass production from forest thinning in North American forests – A meta-analysis. Verschuyf, J., S. Riffell, D. Miller, T. Wigley. Forest Ecology and Management 261 (2011) 221–232	2011	Meta-analysis of 33 studies. Multiple areas	Multiple species and taxa	Yes	Abstract: Demand for alternative energy sources has led to increased interest in intensive biomass production. When applied across a broad spatial extent, intensive biomass production in forests, which support a large proportion of biodiversity, may alter species composition, nutrient cycling and subsequently biodiversity. Because forest thinning and fuels treatment thinning are viewed as possible wide-spread biomass harvest options, it is important to understand what is known about forest biodiversity response to these practices and what additional information is needed by forest managers and policymakers. Therefore, we summarized documented relationships between forest thinning treatments and forest biodiversity from 505 biodiversity effect sizes (incl. taxa and guild abundance and species richness measures) from 33 studies conducted across North America. We used meta-analysis to summarize biodiversity response by region, taxa and harvest treatments. Biodiversity responses included species richness, diversity, abundance of taxa or groups of species (guilds) and abundance of individual species for birds, mammals, reptiles, amphibians, and invertebrates. Forest thinning treatments had generally positive or neutral effects on diversity and abundance across all taxa, although thinning intensity and the type of thinning conducted may at least partially drive the magnitude of response. Our review highlights the need for more research to

Title/Authors/ Journal/Source	Date	Description/Type/ Scope/Location	Resources/ Species	Peer review	Comments on Document, Abstract, Notable Findings
					determine effects of thinning on amphibians and reptiles and manipulative experiments designed to test the effects of biomass removal on biodiversity.
BIRDS					
Short-term effects of fire and fire surrogate treatments on foraging tree selection by cavity-nesting birds in dry forests of central Washington Lyons, A., W.L. Gaines, J. F. Lehmkuhl, R.J. Harrod. Forest Ecology and Management 255 (2008) 3203–3211	2008	Central Washington state.		Yes	Abstract: Dry forests of Washington are becoming increasingly susceptible to broad scale stand replacement fire and insect and disease epidemics. In response, land managers implement fuel reduction strategies. These situations could potentially affect numerous wildlife species, including cavity nesting birds. Much information exists on nesting requirements of cavity-nesters, while little information is available on their foraging requirements, or how changes to their habitat affect foraging. We examined short-term responses of cavity-nesting birds in dry conifer forests of Washington, to fuel reduction treatments in 2004 and 2005, as part of the National Fire–Fire Surrogate Project (FFS). Our objective was to determine if altering the forest stand through mechanical thinning or prescribed burning or a combination of the two would alter foraging tree selection. We used linear logistic regression and Akaike’s Information Criteria (AIC) to model foraging tree selection and to analyze the effects of treatments on foraging tree selection. Model averaged parameter estimates suggested that cavity-nesting birds selected for large diameter trees and FFS treatments had a positive impact on foraging for nuthatches and woodpeckers. Birds were more likely to be observed foraging in treated stands and the positive relationship was strongest in stands that received a combination of thinning and burning treatments. Enhanced foraging conditions in the thin–burn treatment may have resulted from a more complete removal of small trees, while the prescribed burn was so low-intensity, it did not remove many small trees. Bird groups selected for trees at least 1.6 times as large in diameter in treated stands as compared to control stands. Our results indicate activities such as thinning and burning may best enhance foraging habitat for bark gleaning species as a whole. Our data suggests that some important treatment design considerations include the removal of small trees and the retention of large trees and snags (>40 cm dbh) that provide important foraging substrate and nesting habitat.
Seavy, N. , J. Alexander and P. Hosten. 2008. Bird community composition after mechanical mastication fuel treatments in southwest Oregon oak	2008	Southwest Oregon		Yes	Abstract: To evaluate ecological effects of vegetation management in SW Oregon oak woodlands and chaparral, we compared bird abundance and vegetation structure at four untreated stands and four stands where shrub cover had been reduced by using mechanical mastication thinning. Treated stands had less shrub cover than untreated stands. Three bird

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<p>woodland and chaparral. Forest Ecology and Management 256, no. 4: 774–778.</p>					<p>species were consistently more abundant on untreated stands. Species that were more abundant on untreated stands were associated with shrub cover, while those that tended to be more abundant on treated stands were associated with open areas, providing further evidence that the treatments were responsible for the observed differences in bird community composition. These results demonstrate a stronger response of shrub-associated species than was documented in an earlier study of smaller-scale shrub removal treatments. This difference suggests that managers can design treatment prescriptions that benefit particular species by altering the size and shape of project areas as well as the tools that are used to reduce shrub cover (e.g., mechanical vs. manual treatments).</p>
<p>Alexander, JD, NE Seavy, and PE Hosten. 2007. Using conservation plans and bird monitoring to evaluate ecological effects of management: An example with fuels reduction activities in southwest Oregon. Forest Ecology and Management 238 (2007) 375–383.</p>				<p>Yes</p>	<p>Abstract: Increasingly, regional conservation plans are using information about how animals respond to changes in habitat characteristics to provide guidelines for management. However, the ability of these plans to effectively guide management remains largely untested. To test a regional bird conservation plan developed by Partners in Flight, we compared bird abundance in untreated stands to that of stands where shrub cover had been reduced to lower the risk of fire. We used these data to evaluate whether birds identified as focal species in the conservation plan increased or decreased in abundance as a result of the treatments. Over a two-year period, two of 12 Partners in Flight oak woodland and chaparral focal species were more abundant at treated units in both years; no species were consistently less abundant at treated units in both years. These results suggest small-scale (7–42 ha) treatments are consistent with the objectives identified in the Partners in Flight regional conservation plan because they benefited species associated with edges, but did not have negative effects on shrub-associated species. We suggest that this is a result of the small size of treatments and the retention of shrub patches in treated areas. An alternative explanation is that the bird/habitat relationships used to develop the conservation plans do not apply in this study area. We tested this hypothesis by comparing the correlations between habitat characteristics and bird abundance with the information in the conservation plans. In all but one case, the direction of the correlation agreed with information in the conservation plan. This project illustrates that even though the ability of conservation plans to predict the ecological effects of management activities may be limited, they can play an important role in interpreting the results of ecological monitoring.</p>

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Variability in Nest Density, Occupancy, and Home Range Size of Western Bluebirds after Forest Treatments S. Hurteau, T. Sisk, B. Dickson, and W. Block. <i>Forest Science</i> 56(1) 2010. P. 131-138.	2010	Northern Arizona ponderosa pine forests	Western bluebirds	Yes	Abstract: Complex land use and fuels management histories have resulted in significant changes in composition, structure, and function of southwestern forests and subsequent changes in the extent and quality of wildlife habitats. We evaluated how several currently used fuel reduction treatments (e.g., mechanical thinning and prescribed fire alone and in combination) affect nest attributes, nest density, nest tree occupancy, and home range size of Western Bluebirds in ponderosa pine dominated forests of northern Arizona. Nest attributes, such as number of eggs or nestlings, varied among treatments, but did not differ statistically. Western Bluebird nest density was significantly influenced by treatment, with densities higher in treated areas, even though snag density was lower in treated areas than in control areas. The average (SE) area of the 50% contour, across all treatment units, was 0.42 0.07 ha, and the average area of the 90% contour was 2.36 0.30 ha. Home range sizes for both probability contours evaluated were 1.5 times larger in the thin-only treatments than in the control units. Conversely, home range area in thin-and-burn treatments was approximately 30% smaller than in control units. The largest home ranges occurred in the burn-only treatments. Our results suggest that forest treatments, such as thinning and prescribed fire are, in general, beneficial to Western Bluebirds, but that low snag retention may be problematic in areas receiving prescribed fire as part of their treatment action.
Stephens, J., and J. Alexander. 2011. Effects of fuel reduction on bird density and reproductive success in riparian areas of mixed-conifer forest in southwest Oregon. <i>Forest Ecology and Management</i> 261, no. 1: 43-49.	2011			Yes?	Overall, results suggest that fuel reduction in riparian areas as compared with typical upland treatments with buffers had a small effect on bird density and a near-term effect on reproductive success. Additional study of fuel reduction in riparian areas is warranted because of its effectiveness in reducing the risk of unnaturally severe wildfire and, correspondingly, the potential benefit to bird communities over the long-term.
REPTILES & AMPHIBIANS					
Bury, R.B. Wildfire, Fuel Reduction, and Herpetofaunas across Diverse Landscape Mosaics in Northwestern Forests <i>Conservation Biology</i> , Pages 968–975 Volume 18, No. 4, August 2004	2004		Reptiles, amphibians	Yes	Abstract (slightly condensed): The herpetofauna (amphibians and reptiles) of northwestern forests (U.S.A.) is diverse, and many species are locally abundant. Most forest amphibians west of the Cascade Mountain crest are associated with cool, cascading streams or coarse woody material on the forest floor, characteristics of mature forests. Extensive loss and fragmentation of habitat resulted from logging across approximately 80% of stands in Oregon. There is a complex landscape mosaic and overlap of northern and southern biotic elements in the

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					<p>Klamath-Siskiyou Region along the Oregon and California border, creating a biodiversity hotspot. The region experiences many low-severity fires annually, punctuated by periodic major fires, including the Biscuit fire, the largest in North America in 2002. In the fire's northern portion, severe fire occurred on >50% of stands of young, managed trees but on only about 25–33% of old-growth stands. This suggests that the legacy of timber harvest may produce fire-prone stands. Calls for prescribed fire and thinning to reduce fuel loads will remove large amounts of coarse woody material from forests, which reduces cover for amphibians and alters nutrient inputs to streams. Our preliminary evidence suggests no negative effects of wildfire on terrestrial amphibians, but stream amphibians decrease following wildfire. Most reptiles are adapted to open terrain, so fire usually improves their habitat. Today, the challenge is to maintain biodiversity in western forests in the face of intense political pressures designed to “prevent” catastrophic fires. We need a dedicated research effort to understanding how fire affects biota and to proactively investigate outcomes of fuel-reduction management on wildlife in western forests.</p>
<p>Greenberg C., and T. Waldrop Short-term response of reptiles and amphibians to prescribed fire and mechanical fuel reduction in a southern Appalachian upland hardwood forest Forest Ecology and Management 255 (2008) 2883–2893</p>	2008	Green River Game Land, Polk County, North Carolina	Reptiles, amphibians	Yes	<p>Abstract: Compared effects of 3 fuel reduction techniques and a control on relative abundance and richness of reptiles and amphibians using drift fence arrays with pitfall and funnel traps. 3 replicate blocks were established at the Green River Game Land, Polk County, North Carolina. Each replicate block contained four experimental units that were each approximately 14 ha in size. Treatments were prescribed burn (B); mechanical understory reduction (M); mechanical + burn (MB); and controls (C). Mechanical treatments were conducted in winter 2001–2002, and prescribed burns in March 2003. Hot fires in MB killed about 25% of the trees, increasing canopy openness relative to controls. Leaf litter depth was reduced in B and MB after burning, but increased in M due to addition of dead leaves during understory felling. The pre-treatment trapping period was short (15 Aug–10 Oct 2001) but established a baseline for post-treatment comparison. Post-treatment (2002–2004), traps were open nearly continuously May–Sept. We captured a total of 1308 species of 13 amphibians, and 335 reptiles of 13 species. Relative abundance of total salamanders, common salamander species, and total amphibians was not changed by the fuel reduction treatments. Total frogs and toads (anurans) and <i>Bufo americanus</i> were most abundant in B and MB; however, the proximity of breeding sites likely affected our results. Total reptile abundance and eastern fence lizard abundance were highest in MB after burning, but differed</p>

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					significantly only from B. Mean lizard abundance in MB was highest in 2004 and higher than in other treatments, but differences were not statistically significant. Results indicate that a single application of the fuel reduction methods studied will not negatively affect amphibian or reptile abundance or diversity in southern Appalachian upland hardwood forest. Study further suggests that high-intensity burning with heavy tree-kill, as in MB, can be used as a management tool to increase reptile abundance – particularly lizards – with no negative impact on amphibians, at least in the short-term.
Response of Reptiles and Amphibians to Repeated Fuel Reduction Treatments Mattews, C., C.E. Moorman, C.A. Greenberg, T.A. Waldrop. Journal of Wildlife Management 74(6):1301–1310; 2010; DOI: 10.2193/2008-513	2010	Green River Game Land (GRGL) in the southern Appalachian Mountains of Polk County, North Carolina	Reptiles, amphibians	Yes	Abstract: Recent use of prescribed fire and fire surrogates to reduce fuel hazards has spurred interest in their effects on wildlife. Studies of fire in the southern Appalachian Mountains (USA) have documented few effects on reptiles and amphibians. However, these studies were conducted after only one fire and for only a short time (1–3 yr) after the fire. From mid-May to mid-August 2006 and 2007, we used drift fences with pitfall and funnel traps to capture reptiles and amphibians in a control and 3 replicated fuel-reduction treatments: 1) twice-burned (2003 and 2006), 2) mechanical understory cut (2002), and 3) mechanical understory cut (2002) followed by 2 burns (2003 and 2006). We captured fewer salamanders in mechanical + twice-burned treatment areas than in twice-burned and control treatment areas, but we captured more lizards in mechanical + twice-burned treatment areas than in other treatment areas. Higher lizard captures in mechanical + twice-burned treatment areas likely was related to increased ground temperatures and greater thermoregulatory opportunities. Higher and more variable ground temperatures and faster drying of remaining litter and duff may have led to fewer salamander captures in mechanical + twice-burned treatment areas. Our longer term results, after 2 prescribed burns, differ from shorter term results. After one prescribed burn at the same site, eastern fence lizard captures were greater in mechanical + burn treatment areas but salamander captures did not differ among treatment areas. Our results indicate that multiple (L2) fuel-reduction treatments that decrease canopy cover may benefit lizards but negatively affect salamanders.
MAMMALS					
Small Mammal Responses to Fine Woody Debris and Forest Fuel Reduction in Southwest Oregon Manning, J., and W.D. Edge	2008	Applegate Adaptive Management Area, Siskiyou Mountains, SW Oregon	Small mammals	Yes	Despite its importance for wildlife, most forests in the Pacific Northwest contain low volumes of large downed wood compared to fine woody debris (FWD). We used a replicated experiment to compare short-term responses of deer mice and western red-backed voles among 3 arrangements of FWD: piled, lopped and scattered, and pile burning, a

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Journal of Wildlife Management Volume 72, Issue 3, pages 625–632, April 2008					commonly used method of fuel reduction in commercial Douglas fir forests in southwest Oregon, USA. We assessed habitat use, density, and survival of mice and voles during 2 consecutive summers (Jun—Aug 1999 and 2000). Both mice and voles used FWD cover disproportionately from its availability, and they differed in their responses to specific FWD arrangements. Mice used piled FWD (proportional use = 37.0%, 90% CI = 33.0–44.0) 43% more than expected (26.0). Number of mice captured (\bar{x} = 1.9 mice, 90% CI = 1.5–2.5) and index of home range size (\bar{x} = 4.8 m, 90% CI = 0.7–8.9) at individual FWD piles decreased up to 16% and increased up to 50%, respectively, for each 1-m increase in distance from piles. Voles used all FWD cover classes in proportion to availability, but number of voles captured increased slightly (\bar{x} = 0.016 voles/m, 90% CI = 0.001–0.031) for each 1-m increase in distance from piles. Piled FWD had no discernable effect on population density and apparent survival of mice, but analyses had low power (0.25, 0.67). Our results suggest that piling FWD would benefit deer mice, whereas lopped and scattered FWD might benefit voles. Thus, a combination of methods to reduce fire risk should be considered to accommodate multiple small mammal species.
Long, R. A.; Rachlow, J.L.; Kie, J.G. Effects of Season and Scale on Response of Elk and Mule Deer to Habitat Manipulation Journal of Wildlife Management. 72(5): 1133-1142	2007	Starkey Experimental Forest and Range in northeastern Oregon	Elk, mule deer	Yes	Manipulation of forest habitat via mechanical thinning or prescribed fire has become increasingly common across western North America. Nevertheless, empirical research on effects of those activities on wildlife is limited, although prescribed fire in particular often is assumed to benefit large herbivores. We evaluated effects of season and spatial scale on response of Rocky Mountain elk and mule deer to experimental habitat manipulation at the Starkey Experimental Forest and Range in northeastern Oregon, USA. From 2001 to 2003, 26 densely stocked stands of true fir and Douglas-fir were thinned and burned and 27 similar stands were left untreated to serve as experimental controls. We used location data for elk and mule deer collected during spring and summer of 1999-2006 to compare use of treated and untreated stands and to model effects of environmental covariates on use of treated stands. In spring, elk selected burned stands and avoided control stands within the study area (second-order selection; large scale). Within home ranges (third-order selection; small scale), however, elk did not exhibit selection. In addition, selection of treatment stands by elk in spring was not strongly related to environmental covariates. Conversely, in summer elk selected control stands and either avoided or used burned stands proportional to their availability at the large scale; patterns of space use within home ranges were similar to those observed in spring. Use of treatment stands by elk in summer was related to topography, proximity

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					to roads, stand size and shape, and presence of cattle, and a model of stand use explained 50 percent of variation in selection ratios. Patterns of stand use by mule deer did not change following habitat manipulation, and mule deer avoided or used all stand types proportional to their availability across seasons and scales. In systems similar to Starkey, manipulating forest habitat with prescribed fire might be of greater benefit to elk than mule deer where these species are sympatric, and thus maintaining a mixture of burned and unburned (late-successional) habitat might provide better long-term foraging opportunities for both species than would burning a large proportion of a landscape.
CARBON EMISSIONS, AIR QUALITY					
Manomet Center for Conservation Sciences. Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Dept of Energy Resources. Walker, T. (Ed.), Cardellichio, P., Colnes, A., Gunn, J., Kittler, B., Perschel, R., Recchia, C., Saah, D., & Walker, T. Natural Capital Initiative Report NCI-2010-03. Brunswick, ME.	2010	Massachusetts, USA Analysis included potential biomass supplies from adjacent areas.	Carbon cycling, budgeting		
Greenhouse gas and air pollutant emissions of alternatives for woody biomass residues FINAL DRAFT V2.0 Lee, C., P. Erickson, M. Lazarus, G. Smith. Stockholm Environment Institute (SEI) for Olympic Region Clean Air Agency (ORCAA)	2010	Report and Woody Biomass Emissions Calculator provide regional air managers and decision makers in PNW and Alaska with tools for evaluating air emissions implications of alternatives for managing woody biomass residues from forest practices. Considers alternative fates for woody biomass residues and their implications on air		?	

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		emissions associated with both global climate change (carbon dioxide, methane, nitrous oxide) and local air pollution (fine particulates and carbon monoxide).			
Review & Critique of SEI Life Cycle Analysis of Alternative Uses for Logging Slash Morris, J., S. Suh, H. S. Matthews, M. Z. Jacobson, S. Brown, M. Booth.	2011	Critique of Stockholm Environment Institute (SEI) study & conclusions.			Authors assert that errors, omissions, biased assumptions and limited perspective of SEI study will result in policy decisions promoting biomass combustion and gasification that will have impacts on climate, human health and ecosystems that are more deleterious than study conclusions suggest. Authors assert that SEI's emissions estimates for important air pollutants and their conclusions are at odds with scientific literature, and that data was cherry picked and information omitted.
Marshall, Liz, and Alexia Kelly. 2010. The Time Value of Carbon and Carbon Storage: Clarifying the terms and the policy implications of the debate. WRI Working Paper. World Resources Institute, Washington, DC. 23 pp. http://www.wri.org/publications	2010	Discusses "time value" of carbon, i.e. relative values & costs of carbon sequestered or emitted now, vs. carbon sequestered or emitted at some point in the future. "Temporary" carbon storage, in this discussion means storage for less than 100 years. The importance of the concept of temporary storage, and how relative values of emissions at different points in time compare, plays out across a number of different policy arenas, including: <ul style="list-style-type: none"> • Biofuels greenhouse gas accounting: Accounting for paths of carbon emissions associated with biofuels production in assigning a single greenhouse gas content figure for a gallon of biofuel. 			Discusses issues & implications associated with temporary carbon storage (e.g., 50 yrs); attempts to articulate whether or not temporary carbon storage has a value, what the nature of that value is, and how it can be used to inform policy design in a variety of relevant arenas for GHG accounting & climate policy. Specifically explores implications of a positive valuation of temporary storage in 3 contexts: lifecycle GHG accounting for biofuels, agricultural offsets accounting, and deferred emissions from reduced deforestation & forest degradation mechanisms. A couple of broad generalizations emerge from an examination of the social cost of carbon numbers themselves. Of critical significance is the fact that temporary storage value is highly sensitive to the length of storage as well as to the weighting structure used to aggregate and compare the monetized costs and benefits associated with climate change over time. Illustrating this sensitivity using available numbers highlights the importance of incorporating such considerations into policy design (in the case of sensitivity to project duration) and transparent policy decision making (in the case of discount rate selection) when dealing with issues related to temporary carbon storage.

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		<ul style="list-style-type: none"> • Reduced emissions from deforestation and forest degradation: Assigning a value to deferred deforestation, where deforestation rates are lowered, but permanent protection is not guaranteed. • Biological offsets (e.g., in agriculture and forestry): Defining the equivalence of temporary and permanent offsets in order to determine how/whether they should be tradable within the same market. • Accounting for long-lived versus short-lived forest products in land-use change or product-based accounting: Determining whether/how carbon emission values assigned to long-lived forest products such as timber should differ from shorter-term carbon emissions, such as those arising through burning, in determining the carbon impact of a forestry project. • Allowance banking and borrowing: Determining an appropriate rate of trade across time for emissions credits that can be banked or borrowed. 			

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Characterizing Lessons Learned from Federal Biomass Removal Projects. Joint Fire Science 07-32-2-08. Becker, D., D. Abbas, K. Halvorsen, P. Jakes, S. McCaffrey, C. Moseley.		Synthesis, western U.S.			Includes discussion of how environmental concerns have affected federal biomass removal projects. In areas (such as central Oregon) where there are concerted efforts among stakeholders to collaborate and educate, concerns over environmental impacts have been reduced. (P. 37)
The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest Finkral, A. and A.M. Evans. Forest Ecology and Management Volume 255, Issue 7, 20 April 2008, Pages 2743-2750	2008			Yes	<p>Abstract: Vast areas of ponderosa pine (forest in the western U.S. have become unnaturally dense because of relatively recent land management practices that include fire suppression and livestock grazing. In many areas, thinning treatments can re-establish natural ecological processes and help restore ecosystem structure and function. Precipitous global climate change has focused attention on the carbon storage in forests. An unintended consequence of fire suppression has been the increased storage of carbon in ponderosa stands. Thinning treatments reduce standing carbon stocks while releasing carbon through the combustion of fuel in logging machinery, burning slash, and decay of logging slash and wood products. These reductions and releases of stored carbon must be compared to the risk of catastrophic fire burning through the stand and releasing large quantities of carbon to the atmosphere to more fully understand the costs and benefits – in carbon terms – of forest restoration strategies.</p> <p>This study examines the effect of a restoration thinning treatment on the carbon stock of a ponderosa pine forest. The total pre-treatment above-ground carbon stock was 48,880 kg C ha⁻¹ and the post-treatment stand had 36,420 kg C ha⁻¹. The carbon stock in trees across the stand ranged from 28,560 to 67,560 kg C ha⁻¹ pre-treatment and from 11,970 to 55,510 kg C ha⁻¹ post-treatment. 8240 kg C ha⁻¹ was removed from the site and sold to the wholesale firewood market (plot values ranged from 4890 to 12,310 kg C ha⁻¹), 91 kg C ha⁻¹ was released from the combustion of fuel in harvesting operations and trucking, and processing of the firewood required carbon released 33 kg C ha⁻¹. Burning of slash piled on site released 4140 kg C ha⁻¹ (plot values ranged from 2920 to 6900 kg C ha⁻¹). We estimated that in a stand-replacing fire, the treated stand would release 2410 kg C ha⁻¹ less to the atmosphere than the untreated stand. However, the thinning treatment resulted in stand structural changes that make the stand less likely to support a crown fire and therefore more likely to avoid the carbon releases associated with crown fires, even under extreme fire conditions. On balance, the</p>

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					thinning treatment released 3114 kg C ha ⁻¹ . If the wood removed from the site had been used in longer-lasting products, the thinning could have resulted in net carbon storage on the order of 3351 kg C ha ⁻¹ .
<p>Carbon Benefits from Fuel Treatments Cathcart, J., A. Ager, A. McMahan, M. Finney, and B. Watt. In: Jain, T; R. Graham and J. Sandquist, J., tech. eds. 2010. Integrated management of carbon sequestration and biomass utilization opportunities in a changing climate: Proceedings, 2009 National Silviculture Workshop; June 15-18; Boise, ID. Proceedings RMRS-P-61. Fort Collins, CO: USDA, Forest Service, Rocky Mountain RS. 351 p.</p>	2010	<p>169,200-acre Drews Creek watershed, Goose Lake basin, Fremont-Winema National Forest, south-central Oregon.</p> <p>Stands dominated by ponderosa pine 68% of forest land. 17% is in juniper woodlands, predominantly white fir stands about 6%. Smaller stands of lodgepole pine and aspen scattered across the landscape.</p>	carbon		<p>Abstract: Landscape simulation modeling is used to examine whether fuel treatments result in a carbon offset from avoided wildfire emissions. The study landscape was a 169,200-acre watershed located in south-central Oregon. Burn probability modeling was employed under extreme weather and fuel moisture conditions. Expected carbon stocks post-treatment, post-wildfire were calculated for all stands on the treated landscape; post-wildfire on the untreated landscape. Results show a negative carbon offset initially—the known reduction of carbon stocks from treatment is greater than expected carbon benefit from reduced wildfire emissions. Treatment may break even as a carbon offset after 9 years.</p>
<p>Ager, A. A., Finney, M. A., McMahan, A., and Cathcart, J. 2010. Measuring the effect of fuel treatments on forest carbon using landscape risk analysis Nat. Hazards Earth Syst. Sci., 10, 2515-2526, 2010 www.nat-hazards-earth-syst-sci.net/10/2515/2010/</p>	2010	<p>Southeastern Oregon. More rigorous write-up of project above</p>	carbon	Yes	<p>Abstract: Wildfire simulation modeling was used to examine whether fuel reduction treatments can potentially reduce future wildfire emissions and provide carbon benefits. In contrast to previous reports, the current study modeled landscape scale effects of fuel treatments on fire spread and intensity, and used a probabilistic framework to quantify wildfire effects on carbon pools to account for stochastic wildfire occurrence. The study area was a 68,474 ha watershed located on the Fremont-Winema National Forest in SE Oregon, USA. Fuel reduction treatments were simulated on 10% of the watershed (19% of federal forestland). We simulated 30,000 wildfires with random ignition locations under both treated and untreated landscapes to estimate the change in burn probability by flame length class resulting from the treatments. Carbon loss functions were then calculated with the Forest Vegetation Simulator for each stand in the study area to quantify change in carbon as a function of flame length. We then calculated the expected change in carbon from a random ignition and wildfire as the sum of the product of the carbon loss and the burn probabilities by flame length class. The expected carbon difference between the non-treatment and treatment scenarios was then calculated to quantify the effect of fuel treatments. Overall, results show that the carbon loss from implementing fuel reduction treatments exceeded the expected carbon</p>

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					benefit associated with lowered burn probabilities and reduced fire severity on the treated landscape. Thus, fuel management activities resulted in an expected net loss of carbon immediately after treatment. However, the findings represent a point in time estimate (wildfire immediately after treatments), and a temporal analysis with a probabilistic framework used here is needed to model carbon dynamics over the life cycle of the fuel treatments. Particularly important is the long-term balance between emissions from decay of dead trees killed by fire & carbon sequestration by forest regeneration following wildfire.
<p>An Analysis of Wildfire Fuel Treatments as a Carbon Offset Project Type. California Energy Commission. Publication number: CEC-500-02-004. Kelly, P. and J. Cathcart. The Climate Trust, Oregon Dept of Forestry). 2010.</p>	2010	Addresses project described above with more discussion of the potential for using public lands fuels projects as carbon offsets, and less discussion of details about the Drews Creek project itself.			<p>Abstract: Fuel treatments involve removal of biomass from targeted areas in forested landscape to reduce the risk of uncharacteristically severe wildfires caused by excess biomass in the forest. This report describes a landscape-scale case study in south-central Oregon that modeled the impact of fuel treatments on wildfire behavior and associated CO2 emissions and assesses the project's ability to generate carbon offsets that meet the quality criteria identified by the Offset Quality Initiative. The report makes two primary findings: 1) The case study is likely a carbon-neutral project, meaning that few or no offsets would result from the project activity. 2) While this project type could generate quality offsets, the adoption rate would likely be low due to the current inability to implement quality offset projects on federal lands and the expense of activities required to ensure that the carbon benefit is real and permanent. For these reasons, fuel treatment projects are unlikely to be a viable source of quality offsets. This report recommends that a federal policy decision be made to determine if offset projects can involve federal lands. This is important not only for this project type but for others that hope to utilize waste biomass (e.g., biochar and energy generation projects). This report also encourages development of fuel treatment projects because the risk of uncharacteristically severe wildfires is likely to increase with climate change and such projects provide a host of climate change adaptation and mitigation benefits.</p>
<p>Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning S. Dore, T. Kolb M. Montes-Helu, S. Eckert, B. Sullivan, B. Hungate, J. Kaye, S. Hart, G. Koch, A. Finkral. Ecological Applications, 20(3), 2010, pp. 663–683</p>	2010	Northern Arizona	Carbon	Yes	<p>Abstract: Disturbances alter ecosystem carbon dynamics, often by reducing carbon uptake and stocks. We compared the impact of two types of disturbances that represent the most likely future conditions of currently dense ponderosa pine forests of the southwestern United States: (1) high-intensity fire and (2) thinning, designed to reduce fire intensity. High severity fire had a larger impact on ecosystem carbon uptake and storage than thinning. Total ecosystem carbon was 42% lower at the intensely burned site, 10 years after burning, than at the undisturbed site. Eddy covariance measurements over two years showed</p>

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					<p>that the burned site was a net annual source of carbon to the atmosphere whereas the undisturbed site was a sink. Net primary production (NPP), evapotranspiration (ET), and water use efficiency were lower at the burned site than at the undisturbed site. In contrast, thinning decreased total ecosystem carbon by 18%, and changed the site from a carbon sink to a source in the first post-treatment year. Thinning also decreased ET, reduced the limitation of drought on carbon uptake during summer, and did not change water use efficiency. Both disturbances reduced ecosystem carbon uptake by decreasing gross primary production (55% by burning, 30% by thinning) more than total ecosystem respiration (TER; 33–47% by burning, 18% by thinning), and increased the contribution of soil carbon dioxide efflux to TER. The relationship between TER and temperature was not affected by either disturbance. Efforts to accurately estimate regional carbon budgets should consider impacts on carbon dynamics of both large disturbances, such as high-intensity fire, and the partial disturbance of thinning that is often used to prevent intense burning. Our results show that thinned forests of ponderosa pine in the southwestern United States are a desirable alternative to intensively burned forests to maintain carbon stocks and primary production.</p>
<p>Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems Mitchell, S., M. Harmon, K. O’Connell.2009. Ecological Applications 19 (3) :643-655.</p>	2009	<p>East Cascades ponderosa pine forests (Pringle Falls), west Cascades western hemlock–Douglas-fir forests (H.J. Andrews), and Coast Range western hemlock–Sitka spruce forests (Cascade Head).</p>	Carbon, wildfire	Yes	<p>Abstract: Two forest management objectives being debated in the context of federally managed landscapes in the U.S. Pacific Northwest involve a perceived trade-off between fire restoration and carbon sequestration. The former strategy would reduce fuel (and therefore C) that has accumulated through a century of fire suppression and exclusion which has led to extreme fire risk in some areas. The latter strategy would manage forests for enhanced C sequestration as a method of reducing atmospheric CO₂ and associated threats from global climate change. We explored the trade-off between these two strategies by employing a forest ecosystem simulation model, STANDCARB, to examine the effects of fuel reduction on fire severity and the resulting long-term C dynamics among three Pacific Northwest ecosystems: the east Cascades ponderosa pine forests, the west Cascades western hemlock–Douglas-fir forests, and the Coast Range western hemlock–Sitka spruce forests. Our simulations indicate that fuel reduction treatments in these ecosystems consistently reduced fire severity. However, reducing the fraction by which C is lost in a wildfire requires the removal of a much greater amount of C, since most of the C stored in forest biomass (stem wood, branches, coarse woody debris) remains unconsumed even by high-severity wildfires. For this reason, all of the</p>

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					fuel reduction treatments simulated for the west Cascades and Coast Range ecosystems as well as most of the treatments simulated for the east Cascades resulted in a reduced mean stand C storage. One suggested method of compensating for such losses in C storage is to utilize C harvested in fuel reduction treatments as biofuels. Our analysis indicates that this will not be an effective strategy in the west Cascades and Coast Range over the next 100 years. We suggest that forest management plans aimed solely at ameliorating increases in atmospheric CO2 should forgo fuel reduction treatments in these ecosystems, with the possible exception of some east Cascades ponderosa pine stands with uncharacteristic levels of understory fuel accumulation. <i>Balancing a demand for maximal landscape C storage with the demand for reduced wildfire severity will likely require treatments to be applied strategically throughout the landscape rather than indiscriminately treating all stands.</i>
Emission Reductions from Woody Biomass Waste for Energy as an Alternative to Open Burning Springsteen, B., T. Christofk, S. Eubanks, T. Mason, C. Clavin and B. Storey Journal of the Air & Waste Management Association Vol. 61 January 2011	2011		Air quality	? (Probably)	Abstract: Woody biomass waste is generated throughout California from forest management, hazardous fuel reduction, and agricultural operations. Open pile burning in the vicinity of generation is frequently the only economic disposal option. A framework is developed to quantify air emissions reductions for projects that alternatively utilize biomass waste as fuel for energy production. A demonstration project was conducted involving the grinding and 97-km one-way transport of 6096 bone-dry metric tons (BDT) of mixed conifer forest slash in the Sierra Nevada foothills for use as fuel in a biomass power cogeneration facility. Compared with the traditional open pile burning method of disposal for the forest harvest slash, utilization of the slash for fuel reduced particulate matter (PM) emissions by 98% (6 kg PM/BDT biomass), nitrogen oxides (NOx) by 54% (1.6 kg NOx/BDT), nonmethane volatile organics (NMOCs) by 99% (4.7 kg NMOCs/BDT), carbon monoxide (CO) by 97% (58 kg CO/BDT), and carbon dioxide equivalents (CO2e) by 17% (0.38 t CO2e/BDT). Emission contributions from biomass processing and transport operations are negligible. CO2e benefits are dependent on the emission characteristics of the displaced marginal electricity supply. Monetization of emissions reductions will assist with fuel sourcing activities and the conduct of biomass energy projects.
SOILS					
Maintaining Soil Productivity during Forest or Biomass-to-Energy Thinning Harvests in the			Forest soils, focuses specifically on biomass	Yes	Abstract: Forest biomass thinnings, to promote forest health or for energy production, can potentially impact the soil resource by altering soil physical, chemical, and/or biological properties. The extent and degree of impacts within a harvest unit or across a watershed will

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<p>Western United States Deborah S. Page-Dumroese, Martin Jurgensen, and Thomas Terry WEST. J. APPL. FOR. 25(1) 2010</p>			thinning and removal		<p>subsequently determine if site or soil productivity is affected. Although the impacts of stand removal on soil properties in the western United States have been documented, much less is known on periodic removals of biomass by thinnings or other partial cutting practices. However, basic recommendations and findings derived from stand-removal studies are also applicable to guide biomass thinnings for forest health, fuel reduction, or energy production. These are summarized as follows: (1) thinning operations are less likely to cause significant soil compaction than a stand-removal harvest, (2) risk-rating systems that evaluate soil susceptibility to compaction or nutrient losses from organic or mineral topsoil removal can help guide management practices, (3) using designated or existing harvesting traffic lanes and leaving some thinning residue in high traffic areas can reduce soil compaction on a stand basis, and (4) coarse-textured low fertility soils have greater risk of nutrient limitations resulting from whole-tree thinning removals than finer textured soils with higher fertility levels.</p>
<p>Boyle, S.I., S.C. Hart, J.P. Kaye and M.P. Waldrop. 2005. Restoration and Canopy Type Influence Soil Microflora in a Ponderosa Pine Forest. Soil Science Society of America Journal 69:1627–1638.</p>	2005	Northern Arizona	Forest soils, ponderosa pine ecosystem	Yes	<p>Abstract: In ponderosa pine (<i>Pinus ponderosa</i> Dougl. ex Laws.) forests of the western USA, fire exclusion by Euro-American settlers facilitated pine invasion of grass openings, increased forest floor detritus, and shifted the disturbance regime toward stand-replacing fires. We evaluated the impacts of two replicated ecological restoration treatments involving tree thinning alone (thinning restoration) and a combination of tree thinning, forest floor reduction, and prescribed burning (composite restoration) on soil microbial activity, biomass, and function approximately 8 yr after initial treatments. Microbial-N levels in the two restoration treatments were not significantly different from the control during either the dry or wet periods of the growing season. Soil respiration measured in situ was significantly higher in the restoration treatments than in the control only during the dry period, while soil enzyme activities were generally higher in the composite restoration treatment than in the thinning restoration or control treatments during the wet period. Community-level physiological profiles suggested differences in the physiological capacities of bacteria and fungi in the composite restoration treatment compared with the other treatments. We also compared microbial characteristics under different canopy types to evaluate the impacts of pine invasion and establishment in grass openings on soil microorganisms. Soil respiration rates (dry period only) and enzyme activities (wet period only) were higher in grass openings than under presettlement trees, with intermediate values found under postsettlement pines that have invaded grass areas. Taken together, our</p>

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<p>Water and Nutrient Outflow Following the Ecological Restoration of a Ponderosa Pine-Bunchgrass Ecosystem Kaye, J., S. Hart, R. Cobb, J. Stone. Restoration Ecology Volume 7, Issue 3, pages 252–261, SEPTEMBER 1999</p>	1999	Northern Arizona		Yes	<p>results suggest that restoration treatments have long-term impacts on the soil microflora in these forests.</p> <p>Abstract: In the late 1800s, fire suppression, livestock grazing, and a wet and warm climate led to an irruption of ponderosa pine regeneration in the southwestern United States. Pines invaded bunchgrass openings, causing stand structure changes that increased the number of stand-replacing fires. Ecological restoration, via thinning and prescribed burning, is being used to decrease the risk of stand-replacing fires and ameliorate other effects of pine invasion. The effects of aboveground restoration on belowground processes are poorly understood. We used a hydrologic model and soil water nutrient concentrations, measured monthly below the rooting zone, to estimate restoration effects on nutrient losses by leaching from a mature ponderosa pine forest near Flagstaff, AZ. Replicated restoration treatments included thinning to pre-1880 stand densities (partial restoration), thinning plus forest floor fuel reduction followed by a prescribed burn (complete restoration), and an untreated control. Water outflow occurred only between January and May and was lowest from the control (47 and 28 mm in 1995 and 1996) and highest from the partial restoration treatment (67 and 59 mm in 1995 and 1996). The concentrations (typically <0.10 mg/ L) and estimated annual losses (<0.02 kg/ha) of NH₄⁺-N, PO₄³⁻-P, and organic P were similar among treatments. Nitrate and organic N concentrations were as high as 0.80 mg N/L; however, these concentrations and estimated annual losses (<0.13 kg N/ha) were similar among treatments. Our results suggest that restoration will not enhance nutrient loss by leaching or alter stream chemistry in ponderosa pine forests.</p>
<p>Post-fire legacy of ectomycorrhizal fungal communities in the Swedish boreal forest in relation to fire severity and logging intensity Dahlberg, A., J. Schimmel, A. Taylor, H. Johannesson. Biological Conservation 100, (2), Aug. 2001, Pp. 151-161</p>	2001	Sweden		Yes	<p>Swedish foresters are placing increasing reliance in burning of forestland and green tree retention, in order to enhance biodiversity in the Swedish boreal forests. However, much remains to be learned about how to optimize nature conservation goals by different logging and burning procedures. We monitored the survival of ectomycorrhizal (EM) fungi as mycorrhizas, at a clear-cut, a seed tree stand and an uncut stand of Scots pine in central Sweden, with and without burning at two levels of fire severity. The abundance of mycorrhizas and the EM fungal diversity declined with increased logging intensity and with increased depth of burn. Deep burning fires in combination with logging or fire-caused tree mortality can kill much of the existing EM community. Logging intensity, fire intensity and fire severity are all factors that can be manipulated, thus changing the effects on EM fungi and other soil biota.</p>

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Outerbridge, R.A. and J.A. Trofymow. 2009. Forest management and maintenance of ectomycorrhizae: A case study of green tree retention in south-coastal British Columbia. BC Journal of Ecosystems and Management 10(2):59–80.	2009			Yes	
Dahlberg, A. J. Schimmel, A.F. Taylor and H. Johannesson. 2001. Post-fire legacy of ectomycorrhizal fungal communities in the Swedish boreal forest in relation to fire severity and logging intensity. Biological Conservation Vol. 100, Issue 2, pp. 151-161.	2001	Scots pine forest, central Sweden	Forest soils, mycorrhizae	Yes	Abstract: Swedish foresters are placing increasing reliance in burning of forestland and green tree retention, in order to enhance biodiversity in the Swedish boreal forests. However, much remains to be learned about how to optimize nature conservation goals by different logging and burning procedures. We monitored the survival of ectomycorrhizal (EM) fungi as mycorrhizas, at a clear-cut, a seed tree stand and an uncut stand of Scots pine in central Sweden, with and without burning at two levels of fire severity. The abundance of mycorrhizas and the EM fungal diversity declined with increased logging intensity and with increased depth of burn. Deep burning fires in combination with logging or fire-caused tree mortality can kill much of the existing EM community. Logging intensity, fire intensity and fire severity are all factors that can be manipulated, thus changing effects on EM fungi and other soil biota.
Johnston, J.M. and D.A. Crossley. 2002. Forest ecosystem recovery in the southeast US: soil ecology as an essential component of ecosystem management. Forest Ecology and Management Volume 155, Issues 1-3, 1 January 2002, Pages 187-203	2002	Southeastern United States, pine plantations, intensive forestry	Forest soils, loblolly pine	Yes	Abstract: The forestry industry in the southeastern United States relies upon soils that are highly eroded and depleted of their original organic matter and nutrient content. Pro-active land management can ensure continued and possibly increased production and revenue through the management and recovery of the soil resource. With an emphasis on loblolly pine forests, this review integrates land-use history, pine ecology, silviculture, soil ecological research and the implications for forest management into a single discussion. Promoting soil recovery involves knowledge of ecosystem history and disturbance as well as nutrient cycling mechanisms, pools, fluxes and soil forming factors. Research on the rhizosphere is an area that is needed. Recovery of regional soils may confer benefits of drought and disease resistance. The goal of sustainable forestry is compatible with soil recovery; however, the technology and practices of modern forestry deserve thorough evaluation. Emphasis on the continued production of commodities, the agricultural model, is much different from managing for the functioning of healthy forest ecosystems. Many of the practices and outcomes of

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					intensive forest management, including short rotations, harrowing, subsoiling, and burning or removal of logging slash, seem to be at odds with the goal of soil recovery. Best management practices that foster soil recovery include less intensive stand utilization and reduced soil disturbance. Stem-only harvest and longer rotations permit a recovery of soil biodiversity and an accrual of detritus and soil organic matter. Windrowing and similar techniques have dramatic and lasting effects on soil development. No-tillage agriculture as a model for pine plantations is discussed.
CARBON					

Appendix C – Report Methodology

1. Initial work following passage of Oregon SB 1072 (2005 session) was to establish the Forest Biomass Work Group and the Federal Forestland Advisory Group to infuse public process into furthering the discussion around increasing biomass utilization in Oregon.
2. Process for first report: April 2008 through November 2008 the Oregon Department of Forestry sought input from a select group of folks both inside and outside of Oregon to contribute to the literature search, hired a consultant to begin synthesis of literature and then had both and internal and external review of the document with the final report produced in December 2008.
3. Process for second report mimicked the process for the first report. In March of 2011 through September 2011 the Oregon Department of Forestry sought input from a select group of folks both inside and outside of Oregon to contribute to the literature search, hired a consultant to begin synthesis of the literature, and then conducted both and internal and external review of the draft document. The final report was produced on ??