Monitoring plan for the Wasson Creek Ridgetop-to-Estuary Watershed Restoration project

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Contents

Abbreviations and definitions

Ai – Anabranching index.
AND – Anderson wetland, a non-tidal riparian restoration site located just south of Wasson Valley in SSNERR.
BACIPS – Before-after control-impact paired series (sampling design).
BDA – Beaver dam analog.
BLM – Bureau of Land Management.
CAR – Carbon accumulation rate.
CDMO – Centralized Data Management Office.
CoqWA – Coquille Watershed Association.
CTCLUSI – Confederated Tribes of Coos, Lower Umpqua and Siuslaw Indians.
DEQ – Department of Environmental Quality (Oregon).
DBD – Dry bulk density.
DBH – Diameter at breast height.
DO – Dissolved oxygen.
DSL – Department of State Lands (Oregon).
EBEEM – Elevation-Based Estuary Extent Model.
eDNA – Environmental deoxyribonucleic acid.
FIA – Forest Inventory and Analysis.
FSM – Fredrickson South Marsh, a brackish reference marsh in SSNERR.
GHG – Greenhouse gas.
GNSS – Global navigation satellite system (also referred to as global positioning system).
GSD – Ground sampling distance.
HC – Hidden Creek Marsh, a brackish reference marsh in SSNERR.
LCM – Life cycle monitoring.
LIDAR – Light Detection and Ranging.
LOI – Loss-on-ignition.
LWD – Large woody debris.
MHHW – Mean higher high water, the average of all higher high tides during a tidal epoch.
NAVD88 – North American Vertical Datum of 1988. NAVD88 is a geodetic datum that approximates mean sea-level in North America.
NDVI – Normalized difference vegetation index.
NERRS – National Estuarine Research Reserve System, a national system of 30 estuarine reserves located throughout the United States.
NOAA – National Oceanic and Atmospheric Administration, an agency of the Department of Commerce.
ODFW – Oregon Department of Fish and Wildlife
OIMB – Oregon Institute for Marine Biology, the marine station for the University of Oregon located in Charleston, OR.
ORGN – Oregon Real-time GNSS Network.
OWEB – Oregon Watershed Enhancement Board.
RCG – Reed canarygrass.
RSET – Rod surface elevation table.
RTN/RTK-GNSS – Real-time Network/Kinematic Global Navigation Satellite System.
SOSTCMET – Sensor Observation Service – Tom's Creek Meteorological Station.
SSNERR – South Slough National Estuarine Research Reserve.
Stage-0 (zero) – A method of stream restoration where stream development is allowed to proceed without the construction of an incised channel.
SWMP – System Wide Monitoring Program.
TEP – Tillamook Estuary Partnership.
TIR – Thermal infrared.
TNC – The Nature Conservancy.
TOC – Tom's Creek palustrine (non-tidal) freshwater reference marsh in SSNERR.
TOM – Tom's Creek tidal marsh in SSNERR.
UAS/UAV – Un-crewed aerial system/un-crewed aerial vehicles (drone).
USFS – United States Forest Service.
UTM – Universal Transverse Mercator coordinate system.
UVVR – Un-vegetated-to-vegetated ratio.
WIN-EM – Winchester marsh, a reference emergent tidal marsh site in SSNERR.
WIN-TS – Winchester tidal swamp, a tidal swamp reference site southeast of Wasson zone 1 in SSNERR.
WTRP – Winchester Tidelands Restoration Project.
WZ1 – Wasson lowlands, zone 1.
WZ2 – Wasson lowlands, zone 2.
WZ3 – Wasson lowlands, zone 3.
WZ4 – Wasson lowlands, zone 4.
WZ5 – Wasson uplands, zone 5.

1. Introduction

1.1 History of estuarine restoration at South Slough

The South Slough National Estuarine Research Reserve (SSNERR) manages 2,647 hectares (6,542 acres) of estuarine and coastal forested habitat in the South Slough watershed, a major tributary of the Coos Estuary on the southern Oregon coast. SSNERR is the oldest of 30 national estuarine research reserves located in coastal waters across the United States and is a partnership between the Oregon Department of State Lands (DSL) and the National Oceanic and Atmospheric Administration (NOAA). One of only two such reserves in the Pacific Northwest (PNW), SSNERR's mission encompasses coastal management, research, education, stewardship, and habitat protection. The Reserve's 2022-2027 strategic plan identifies goals to "assess, monitor, and manage habitats in the Coos estuary and South Slough watershed in order to characterize conditions and changes in habitat use, condition, and availability" and to "continue to build the ridgetop-to-estuary habitat restoration program". Coastal ecosystems located within SSNERR's management jurisdiction include intertidal and subtidal tideflats, seagrass meadows, emergent tidal marshes, forested and shrub-dominated tidal swamps, non-tidal freshwater wetlands and riparian corridors, and temperate coniferous forest.

The Wasson Valley Restoration Project continues decades of estuarine and riparian restoration implemented by SSNERR that has expanded tidal wetland area and enhanced estuarine functions and services in the Coos Estuary throughout the Winchester Tidelands Restoration Project area (WTRP). Previous tidal wetland restoration projects in the WTRP include Kunz Marsh (restored in 1996), Dalton Marsh (restored in 1998), Fredrickson Marsh (restored in 1998) and Cox Marsh (restored in 1996). Anderson Creek, located just south of Wasson Valley, was restored in 2000 to increase non-tidal riparian habitat in SSNERR.

These restoration projects have significantly increased habitat area for wetland plants and animals, and serve as laboratories for better understanding estuarine wetland restoration and function (e.g., Cornu and Sadro 2002). SSNERR conducts ongoing long-term ecosystem monitoring of restored sites as well as least-disturbed reference sites throughout the South Slough watershed. The Reserve also supports estuarine research by SSNERR staff, academic institutions, and non-profit partners on topics such as estuary sediment dynamics and stratigraphy (Nelson et al. 1996, Wilson et al. 2007, Eidam et al. 2021, Souza 2022), carbon storage and carbon cycling (Blount 2017, Kauffman et al. 2020, Fitch et al. 2022, Schultz et al. 2023, Brown et al. 2024, Poppe et al. 2024, Janousek et al. 2025a,b, Williams et al. 2025), marsh plant ecology (Hoffnagle 1980, Keammerer and Hacker 2013), and estuarine hydrology and water quality (Johnson et al. 2019, Conroy et al. 2020, Eidam et al. 2020, Marin Jarrin et al. 2022, Brand et al. 2025).

1.2 Wasson Creek restoration plan development

Wasson Creek was identified as a high priority restoration site by the Reserve and the broader restoration community (e.g., 2017-2022 South Slough NERR Management Plan, the Strategic Action Plan for Coho Salmon Recovery in the Coos Basin). In 2015, the Oregon Watershed Enhancement Board (OWEB) funded Coos Watershed Association to collaborate with the Reserve and an advisory team to develop a ridgetop-to-estuary restoration plan, which was completed in 2018. In 2020, the Reserve reconvened the technical advisory team to review the project and update restoration techniques using the best available research. The final plans were approved by the Reserve Commission in 2021 (uplands component) and 2022 (remaining components). The major alteration in the restoration plan between initial and final design was the intention to restore Wasson lowlands to a Stage-0 wetland-stream complex rather than a Stage 1 single sinuous thread stream (Cluer and Thorne 2013).

The decision to restore to stage-0 conditions was based on habitat and ecosystem benefits and hydrogeomorphic attributes assessed in the revised stream evolution model by Cluer and Thorne (2013), the stage-0 attributes exhibited at the minimally impacted reference site intended to assess restoration success (Tom's Creek in the Reserve), and successful examples of stage-0 restoration projects such as the Fivemile-Bell restoration techniques implemented and assessed by the US Forest Service (USFS). The revised plan to restore the valley to Stage-0 included grading to a 1% grade line, using a geomorphic grade line analysis developed by the USFS, distributing large woody debris (LWD), and spreading hydrologic flow across the valley floor. Slow velocity of water across the valley floor would transport sediments and create flow pathways through deposition rather than downcutting.

The implementation team modified the stage-0 approach in two significant ways. First, in order to facilitate anadromous fish access during and immediately following restoration, a small fish passage channel (approx. 15 cm. depth, 1.2 m width) was included in the design. Second, beaver dam analogs (BDAs) were planned for channel segments that were not filled during the grading process (Pollock et al. 2023). To minimize concentration of flow, down cutting in the fish passage channel, and to slow water flow, LWD was placed in the channel during implementation. Because concentration of flow was observed in some areas post-restoration while others and were dry, adaptive management actions were taken to help spread water across the valley. These actions included creating additional surface roughness in areas of concentrated flow by both moving and anchoring branches and small trees by hand, and planting higher densities of willow stakes.

1.3 Wasson Creek restoration implementation goals

Wasson Valley is located between Winchester Creek and Seven Devils Road at the southwest end of SSNERR. It is a west-to-east trending steep-sided coastal valley within the South Slough branch of the Coos Estuary. In the early 1900s the valley was converted from emergent and forested wetlands to

Figure 1. Aerial images of Wasson Valley and nearby areas in the South Slough watershed taken in 1939 (left) and 1959 (right). Images from U.S. Army Corps of Engineers.

cropland and pastureland (Figure 1). As part of this conversion, the natural wetland-stream complex of Wasson Creek was replaced with linear ditches that redirected water flow away from riparian wetlands. Prevention of regular flooding in valley wetlands, which impeded the influx of sediments, along with drying out of peat soils, led to compacted and consolidated soils as well as substantial subsidence at Wasson Creek. The upland forests located in the hillslope watershed around Wasson Valley have also been affected by anthropogenic activities. Clearcut timber harvest practices affected upland areas to varying degrees and changed disturbance frequency, creating homogenous, high-density forests with little remaining late-seral habitat.

The Wasson Valley Restoration Project is designed to restore multiple coastal ecosystem types in the Wasson Creek watershed area of the Coos Estuary including estuarine tidal swamp, coastal non-tidal wetland and riparian habitat, and mixed conifer upland forest in the Sitka spruce (*Picea sitchensis*) zone defined by Franklin and Dyress (1973). In Wasson Valley lowlands, restoration goals include a modified stage-0 stream restoration to replace existing agricultural ditches, mechanical removal of non-native vegetation (particularly invasive reed canarygrass (RCG), *Phalaris arundinacea*), planting of native vegetation (especially woody riparian plants and culturally-important species), and expanding tidal swamp habitat at the eastern end of the valley adjacent to Winchester Creek where tidal influence is present. In upland forested areas on Wasson Valley hillsides, restoration goals include variable density thinning of coastal forest to achieve greater structural similarity with more mature forests (Brodie and Harrington 2020).

These restoration actions should lead to increased ecosystem resilience for the southern region of SSNERR in the face of climate change and result in better provision of ecosystem services. The project will also provide a valuable opportunity to test various restoration methodologies for riparian and lowland recovery in estuarine-adjacent areas including modified stage-0 stream restoration, use of BDAs, methods for establishment of tidal swamp, and effectiveness monitoring protocols. Other anticipated outcomes of the project include local training, education and outreach, and the restoration and promotion of cultural resources important to Tribal Nations in southern Oregon.

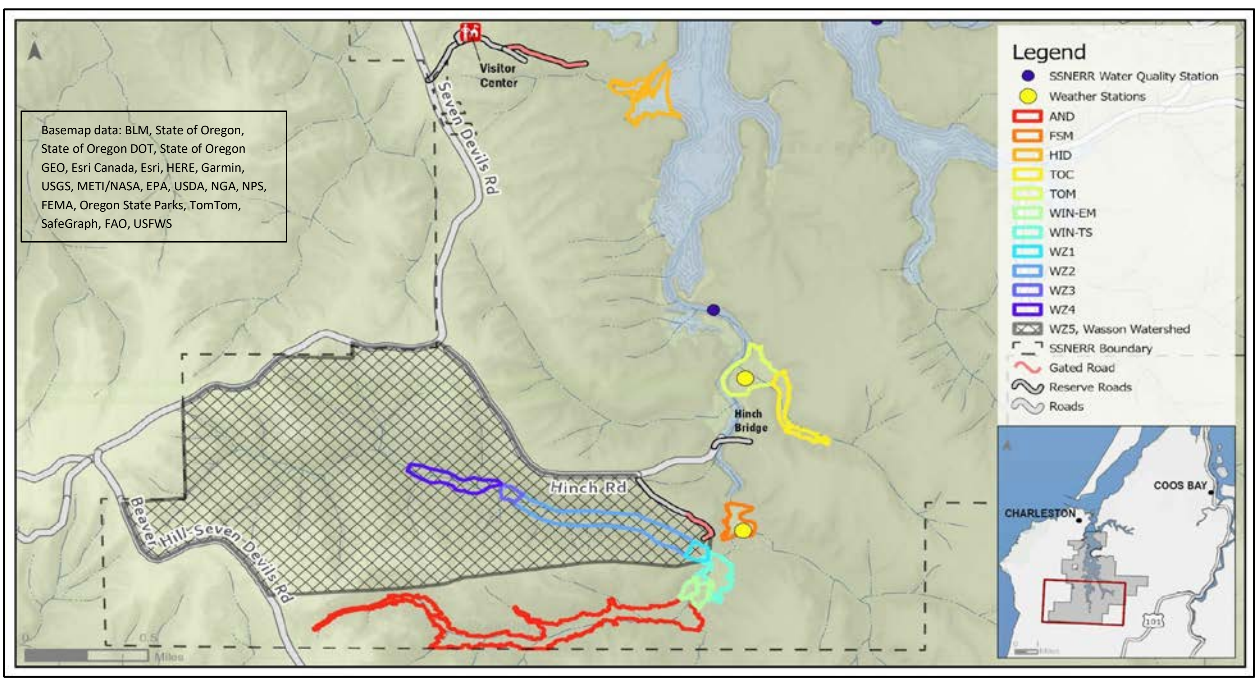

Figure 2. Map of the four lowland zones (WZ1-WZ4), and the forested upland zone (WZ5) undergoing restoration in the Wasson restoration project. Reference sites described in this monitoring plan are also included.

1.4 Introduction to the Wasson Valley watershed and reference sites

For purposes of restoration implementation and monitoring, the valley lowlands are divided into four zones (WZ1-WZ4; Table 1; Figure 2). The forested upland area comprises a fifth zone (WZ5). The lowest elevation zone (WZ1) is adjacent to Winchester Creek and consists of the lower 1.4 ha of the valley (Figure 1). Prior to restoration, WZ1 was partially tidally influenced and consists of some nascent tidal swamp (in the southeast corner), emergent tidal marsh (in the northeastern and easternmost areas near Winchester Creek), and RCG-dominated areas. In this zone, Wasson Creek was a deeply incised ditch that ran along the south edge of the valley. A second smaller agricultural ditch ran along the northern edge of the valley, merging separately with Winchester Creek.

Just west of WZ1, WZ2 comprises the largest area within Wasson Valley. Before restoration, the zone consisted of 12.4 ha of non-tidal, but low elevation, pastureland dominated by emergent vegetation such as RCG and native graminoid species such as small-fruited bulrush (*Scirpus microcarpus*) and slough sedge (*Carex obnupta*). In this zone as well, Wasson Creek continued as a ditch running primarily along the valley's south edge and crossing to the north edge about two thirds of the way up the valley. WZ1 and WZ2 were used for agricultural and grazing activities for many decades prior to acquisition by SSNERR (Figures 1-2).

Table 1. Overview of restored zones in the Wasson restoration project.

Site	Code	Pre-restoration ecosystem type	Primary restoration actions	Anticipated post-restoration ecosystem type
Wasson Valley lowlands, zone 1	WZ1	Mixed nascent tidal swamp and tidal marsh; non-tidal grassland dominated by reed canarygrass	Modified stage-0 (grading and fish passage channel construction); mechanical removal of RCG; LWD and BDA placement; native plantings; nurse crib addition; toe slope construction from graded material	Mature tidal marsh and swamp
Wasson Valley lowlands, zone 2	WZ2	Non-tidal grasslands mostly dominated by reed canarygrass	Modified stage-0 (grading and fish passage channel construction); mechanical removal of RCG; LWD placement; riparian/wetland plantings; toe slope construction from graded material	Non-tidal emergent wetlands and grasslands dominated by native species; riparian wetlands
Wasson Valley lowlands, zone 3	WZ3	Emergent palustrine wetlands and grasslands with mixed assemblage of native and non-native species	LWD and BDA placement; riparian/wetland plantings	Same as pre-restoration with additional riparian wetland component
Wasson Valley lowlands, zone 4	WZ4	Emergent palustrine wetlands and grasslands with mixed assemblage of native and non-native species	Riparian/wetland plantings; LWD placement	Same as pre-restoration with additional riparian wetland component
Wasson uplands, zone 5	WZ5	High density second and third growth coniferous forest	Variable density tree thinning; upland plantings	Lower density, more mature coniferous forest

Zone WZ3 is a small (approximately 1.2 ha) freshwater wetland found upstream of WZ2. WZ3 was characterized by a shallower, braided stream channel network and soils that were generally saturated year-round. RCG was the dominant plant species in this zone, with slough sedge, small-fruited bulrush, and skunk cabbage (*Lysichiton americanum*) occurring in occasional patches. At the west end of WZ3 there is a topographic constriction approximately 15 m wide that separates it from the final valley zone, WZ4. WZ4 is about 5 ha in size and unlike zones WZ1 and WZ2 downstream, has an unmodified channel system that has not been diverted into sidewall ditches. This zone has retained a more dynamic wetland-stream complex and soils that are saturated year-round, and like other areas in Wasson Valley, is dominated by RCG.

WZ5 comprises the forested hill slopes to the north and south of Wasson Valley in the Wasson Creek watershed. These forests, dominated by two species of conifers, Douglas Fir (*Pseudotsuga menziesii*) and Port Orford cedar (*Chamaecyperis lawsoniana*), are dense second or third growth forests. Understory species include huckleberries (*Vaccinium* spp.), salal (*Gaultheria shallon*), and ferns.

For monitoring purposes, several nearby sites in the Winchester Creek area of South Slough are reference wetlands for Wasson Valley zones WZ1-WZ4 (Table 2; Figure 2). Winchester tidal swamp (WIN-TS) is a small remnant tidal swamp located southeast of WZ1 on Winchester Creek. The swamp is vegetated by Sitka spruce (*Picea sitchensis*), with an understory of ferns, slough sedge, and shrubs including huckleberry. Winchester tidal marsh (WIN-EM) is located just south of the swamp and consists of herbaceous emergent vegetation (primarily slough sedge and small-fruited bulrush) and tidal channels (including Winchester Creek) in a low-salinity region of the estuary. Fredrickson South Marsh (FSM) is a high intertidal, emergent brackish marsh located northeast of WZ1 and west of Winchester Creek. It supports diverse vegetation communities dominated by native species such as Pacific silverweed (*Potentilla anserina*), Baltic rush (*Juncus balticus*), and Lyngbye's sedge (*Carex lyngbyei*).

Table 2. Overview of reference sites in the Wasson restoration project.

Site	Code	Ecosystem type	Wasson comparison
Anderson Creek	AND	Restoring tidal and palustrine (riparian) freshwater wetlands	WZ1-WZ4
Winchester Marsh	WIN-EM	Oligohaline tidal marsh	WZ1
Winchester Tidal Swamp	WIN-TS	Forested and scrub-shrub tidal swamp	WZ1
Fredrickson South Marsh	FSM	Mesohaline tidal marsh	WZ1
Tom's Creek Marsh	TOC	Non-tidal freshwater marsh	WZ2, WZ3, WZ4
Tom's Creek Brackish Marsh	TOM	Tidal brackish emergent marsh	WZ1
Hidden Creek Marsh	HC	Tidal brackish emergent marsh	WZ1-WZ4
Uplands in Anderson, Tom's, Winchester, and Dalton Creek watersheds	NA	Mixed conifer forest; Competitive exclusion stand class	WZ5

The Tom's Creek drainage is located northeast of FSM feeding into Winchester Creek and includes two reference sites. On its western end, there is a brackish emergent tidal marsh (TOM) while further upstream the valley narrows to a non-tidal palustrine wetland characterized by beaver activity (TOC). The palustrine wetland has a high water table year-round and plant communities dominated by native species such as soft rush (*Juncus effusus*), slough sedge, cattail (*Typha latifolia*), and Pacific reedgrass (*Calamagrostis nutkaensis*). Hidden Creek marsh (HC), a long-term monitoring site approximately 2.4 km north of Wasson in the mesohaline part of the estuary, is a highly diverse unmodified mature tidal salt marsh. Low marsh here is dominated by seaside arrowgrass (*Triglochin maritima*), pickleweed (*Salicornia pacifica*), fleshy jaumea (*Jaumea carnosa*), and tufted hairgrass (*Deschampsia cespitosa*) while high marsh is dominated by Lyngbye's sedge, seaside arrowgrass, fleshy jaumea, sea milkwort (*Lysimachia maritima*), Baltic rush, Pacific silverweed, and non-native creeping bentgrass (*Agrostis stolonifera*). Finally, Anderson Creek (AND) is a non-tidal riparian wetland located in a valley immediately south of Wasson Valley near the southern administrative border of SSNERR. Anderson Creek was restored in 2000 from ditched, fallow agriculture land and is now dominated by willows (*Salix* spp.) and has heavy beaver activity in the lower portions.

Several of these tidal and non-tidal reference locations (HC, WIN-TS, WIN-EM, TOC, and FSM) are long-term tidal wetland monitoring sites studied by SSNERR staff. Monitoring parameters include wetland elevation, vegetation, accretion and elevation change, and groundwater hydrology. Additional past and ongoing data collection efforts in the area include blue carbon stock, sequestration rate, and greenhouse gas (GHG) emissions measurements (Schultz et al. 2023, Brown et al. 2024, Janousek et al. 2025a,b, Williams et al. 2025); life-cycle monitoring (LCM) for salmon at the northern edge of WIN-TS and near the mouth of AND (Suring et al. 2015); studies of juvenile salmon use and behavior and invertebrate abundance and composition in habitat associated with LWD in tidal channels throughout upper tidal Winchester Creek (Lemke 2006); stream habitat inventories throughout Wasson, reference sites, and other nearby watersheds (Thom et al. 2000); soil characteristics, hydrology, and plant community relationships in freshwater wetlands at AND, TOC, and Wasson (Brophy 2005); and assessments of migration timing and residence time for juvenile coho related to habitat use and growth in upper tidal Winchester Creek (Miller and Sadro 2003).

At TOM, SSNERR operates a long-term meteorological station on a platform elevated above the marsh. Measured parameters are air temperature, precipitation, wind speed and direction, and flux of photosynthetically active radiation (Sensor Observation Service – Tom's Creek Meteorological Station - SOSTCMET, 43.2791°N, 124.3184°W). Additionally, NOAA operates a weather station at the southern end of FSM. Farther north along Winchester Creek, SSNERR operates several water level and water quality monitoring stations as part of the NERR system wide monitoring program (SWMP). The stations collect pH, conductivity, dissolved oxygen, temperature, and turbidity data in Winchester Creek. This network includes station "SOSWIWQ" (43.2824°N, 124.3203°W), which is located about 1.3 km from WZ1. Data from SOSTCMET and water level and quality data from SOSWIWQ are available through the NERRS' Centralized Data Management Office (CDMO) at https://cdmo.baruch.sc.edu/.

For geodetic surveying, several horizontal and vertical control benchmarks are also available in the South Slough area (see Table 7 below). Collectively, extensive datasets are available for a wide range of ecological parameters at reference sites in the vicinity of the Wasson Valley project. A summary of existing datasets for the Wasson watershed and nearby reference sites is given in Appendix A.

1.5 Document objectives

The purpose of this restoration monitoring plan is to outline the monitoring questions, hypotheses, parameters, and methods recommended for the Wasson Valley Restoration Project. This plan is a living document that may be subject to revisions in the future due to changes in funding or staffing, research questions of interest, improvements in methodology, or other unanticipated changes. The approach, parameters, and methods included in this document are intended to generally be compatible with both long-term monitoring protocols already implemented in the NERRS Wetlands and Water Levels Program (formerly "Sentinel Site Program"; NOAA 2012) as well as other estuarine monitoring plans and protocols prepared for estuaries along the Pacific coast (e.g., CoqWA et al. 2024, Janousek and Williams 2024). However, some parameters and their proposed methods are adapted to the specific needs of this project and legacy sampling conducted at SSNERR and therefore may differ from other monitoring programs. While sections of this document are broken out by parameter and method for ease of use, we recognize that in a watershed context, the wetland processes described in this plan are interconnected.

In section 2 we describe the major monitoring questions and hypotheses associated with different restoration zones in the project. In section 3 we describe the overall timeline for restoration implementation and monitoring and the general proposed monitoring approach. Section 4 consists of recommended monitoring methods, each broken out by major parameter (or groups of closely-related parameters). Finally, in section 5 we provide guidelines for data management and analyses. Additional information is provided in appendices and links.

2. Monitoring questions and hypotheses

As a large-scale, whole-watershed project that includes multiple types of coastal and estuarine ecosystems, the Wasson Valley Restoration Project involves many ecological questions, hypotheses, monitoring parameters, and monitoring methods. In this section, we broadly outline key monitoring questions in both the upland and lowlands areas of the project and link them to specific hypotheses, parameters, and methods. We also provide a general timeline of anticipated pre- and post-restoration monitoring. In subsequent sections, we discuss overall sampling design and methods for specific parameters.

Our first group of research questions focuses on changes in *abiotic* factors in Wasson Valley due to implementation of a modified stage-0 stream design, the construction of BDAs, and additional restoration actions such as application of biochar and large-scale removal of invasive vegetation (Table 3). Relevant monitoring parameters for these questions include stream, tidal channel, and groundwater hydrology; water and soil temperature; water quality and salinity; elevation; soil accretion; and channel morphology. Our second group of research questions and hypotheses center on *vegetation responses* to the restoration actions described as well as planting of woody vegetation in several zones in Wasson Valley and tree thinning treatments applied in upland areas of the project (Table 4). Monitoring parameters include vegetation cover, composition, species richness, and woody species survivorship and growth. Our final group of questions centers on *invertebrate, fish, and wildlife* abundance and use of Wasson Valley lowlands and forest habitat in response to restoration actions (Table 5). Monitoring parameters include stream benthic macroinvertebrate communities, presence and abundance of select fish species such as coho salmon and lamprey, and bird and mammal abundance.

*Table 3. Summary of monitoring questions, hypotheses, parameters, and methods for **abiotic factors**. Timelines include: Pre: (0-5 years before restoration), Early post: (0-5 years after restoration), and Late post-restoration (5+ years after implementation).*

Monitoring question	Hypotheses	Parameter(s)	Method(s)	Timeline
Q1. How does modified stage-0 stream restoration change channel morphology, stream habitat characteristics, groundwater hydrology, and stream and soil temperature?	Groundwater levels, and creek and soil temperatures will increase relative to pre-restoration conditions. As channels develop, soil drainage improves, lowering ground water levels. As vegetation recovers (including riparian cover), stream temperature will decrease to pre-restoration conditions.	Groundwater level	Time series in shallow wells §4.02	Pre: 1 yr time series Early post: 1 yr time series at 1, 3, and 5 yr Late post: 1 yr time series every 5 yr
		Water and soil temperature	Steam and subsurface temperature loggers §4.07	
		Sediment movement	LIDAR and multispectral imagery §4.01	Early post: Directly following construction; bi-annually in peak wet and dry seasons years 1-5 Late post: None
		Stream habitat condition	Survey of stream characteristics §4.03 & §4.06	Pre: One sampling Early post: Once between years 2 and 5 Late post: every 5-10 yr
		Channel morphology	RTK-GNSS surveys, aerial imagery §4.04	Pre: One sampling Early post: Directly following restoration (RTK and aerial), then bi-annually until yr 5 (aerial), and in yr 2 (RTK) Late post: Once every 3-5 yr
Q2. How do BDAs affect groundwater hydrology, stream flow, and channel morphology?	Groundwater levels increase (diminishing with lateral distance from stream) and peak stream flow rates decrease following BDA installations. Channel above BDAs widens and becomes shallower over time.	Groundwater level	Time series in shallow wells §4.02	(Same as Q1)
		Stream flow rate	Cross-sectional discharge measurements §4.05	Pre: Monthly during wet season Early post: Monthly during wet season years 1-3 Late post: Intermittently after yr 5
		Channel morphology	RTK and UAV surveys §4.04	(Same as Q1)
Q3. How do water column nutrients, turbidity, temperature and dissolved oxygen (DO) levels change after modified stage-0 restoration?	After restoration, creek temperature, turbidity, and nutrients increase while DO decreases. As Wasson soils stabilize and vegetation grows, parameters will return to pre-restoration conditions.	Water temperature, salinity, dissolved oxygen, turbidity	Time series from sonde in channel §4.03	Pre: 1 yr time series Early post: 1 yr time series in years 1, 3, and 5 Late post: 1 yr time series every 5 yr
		Nutrients: NH_4^+, NO_3^-, NO_2^-, DIN, PO_4^{3-}, SiO_4^{4-}	Replicate water grabs for nutrient analyses §4.03	Pre: Monthly for 1 yr Early post: Monthly for 3 yr Late post: Intermittently after yr 5
Q4. What is the impact of restoration activities on Wasson Valley's elevation, soil accretion, and soil characteristics?	Excavation will lead to an immediate drop in elevation, but elevation will then increase with accretion, which will be higher in tidal areas. Surface soils will acquire greater organic matter content and lower bulk density as wetlands develop in the Valley.	Ground surface elevation	RTK-GNSS surveys §4.01	Pre: One sampling Early post: 1-2 times in the first 5 yr Late post: Once every 3-5 yr
		Soil accretion rates	Feldspar marker horizons §4.09	
		Soil characteristics	Quantitative soil cores §4.08	Pre: One sampling Early post: None Late post: Once about 5-10 yr after restoration
Q5. How do greenhouse gas emissions (GHG) change following restoration?	Methane emissions increase with higher groundwater levels after restoration.	GHG fluxes	Chamber-based GHG fluxes §4.10	Pre: 7-8 samplings over 1 yr Early post: 4 samplings in yr 2 Late post: Every 5 yr
Q6. How does biochar influence nutrients in surface seep water?	Nutrients in water in contact with biochar will decrease and then stabilize over time as biochar becomes saturated with nutrients.	Nutrients: NH_4^+, NO_3^-, NO_2^-, DIN, PO_4^{3-}	Water sample nutrient analysis §4.03	Pre: One sampling before biochar addition Early post: Fortnightly first month, monthly for 1 yr Late post: None
Q7. How does variable density thinning alter fire conditions?	Understory temperatures increase in cut areas and humidity and wood moisture decrease, until canopy and shrub cover reestablishes.	Temperature, humidity, wood moisture	Temperature/humidity loggers, wood moisture meter §4.11	Pre: June through December for one year Early post: June through December in the first 5 yr Late post: Every 5 years

Table 4. Summary of monitoring questions, hypotheses, parameters, and methods for ***vegetation****.*

Monitoring question	Hypotheses	Parameter(s)	Method(s)	Timeline
Q8. How does vegetation change after modified stage-0 restoration? Does mechanical removal and/or woody species planting reduce RCG cover?	Large-scale RCG removal enables short-term increases in native plant cover. Longer-term, native species persistence is greatest where woody species are planted.	Emergent and woody plant cover, species composition, and diversity	Quadrats along permanent vegetation transects; aerial imagery of Wasson Valley §4.13	Pre: 1-2 times Early post: In years 1, 3, and 5 Late post: Every 5 yr
Q9. How does wetland elevation affect survivorship and growth of Sitka spruce swamp woody species?	Nurse cribs with greatest soil volume have highest woody species survivorship and growth rates due to higher moisture available during summer dry months. Woody plant survival and growth is highest at elevations above MHHW.	Woody plant survivorship, stem density, and cover; herbaceous plant cover	Morphometric measurements on plantings in nurse cribs §4.14	Pre: None Early post: September in years 1, 2, 3, and 5 Late post: Every 3 yr
		Crib elevation	RTK-GNSS surveys §4.14	
		soil water content	Soil moisture content §4.14	Pre: None Early post: Monthly May-Oct in years 1, 2, 3, and 5 Late post: None
Q10. Does planting density and diversity of shrub species influence the effectiveness of RCG management?	Higher planting density results in greater native plant cover and greater reduction in RCG cover. Mixed species plots occupy a wider niche space (incl. temporal) and have greater reduction in RCG cover.	Percent cover per species, growth form (woody shrub, grass, herbaceous) and origin (native, exotic).	Circular plot with 3m radius §4.14	Pre: None Early post: In years 1, 3 and 5 Late post: 10 yr, cease if RCG is < 5%
Q11. How do upland forests respond to variable density thinning?	Tree growth rates, crown development, and understory plant diversity and biomass differ among treatments, with greatest effects in gaps, followed by thinned, then skips, relative to controls.	Tree size (DBH) and annual growth, compacted crown ratio, canopy cover, understory plant cover and diversity	Modified Forest Inventory and Analysis (FIA) plots; tree growth rings §4.14	Pre: One sampling Early post: In years 1 and 5 Late post: Once every 10 yr
Q12. How do forest prescriptions influence understory seeding success?	Seeding of forest understory species will be more successful in higher light treatments (gaps and thinned areas) than low light areas (skips and non-treatment areas) and are more diverse than natural recruitment.	Percent cover of herbaceous plants per species	Seeding plots (treatment) and microplots (control) in modified FIA plots §4.14	Pre: One sampling Early post: In years 1, 2, 3 and 5 Late post: Once every 10 yr

*Table 5. Summary of monitoring questions, hypotheses, parameters, and methods for **fauna**.*

Monitoring question	Hypotheses	Parameter(s)	Method(s)	Timeline
Q13. Does stream macro-invertebrate community abundance and composition change after stream restoration?	Density decreases and community composition diverges from reference sites after restoration; these converge toward reference conditions as hydrology and plant communities evolve.	Macroinvertebrate species abundance, composition and diversity	Stream benthic grab sampling §4.18	Pre: One sampling (spring) Early post: Annually (spring) Late post: Once every 5 years (spring)
Q14. Do Wasson Valley restoration actions change beaver use?	Over time, increasing riparian cover and changed hydrology will support greater beaver populations in Wasson Valley.	Density and length of active dams and lodges	Beaver activity surveys§4.16	Pre: One sampling (spring) Early post: Annually (spring) years 1-3 Late post: Once every 3 yr (spring)
		Water level difference	Difference in water level below and above dam §4.15	
Q15. Does restoration affect the composition and diversity of bird communities in Wasson Valley?	Following restoration, bird community composition and diversity becomes more similar to reference sites.	Bird presence, identity, and number of sightings per unit effort.	Bird surveys using point counts and transects §4.15	Pre: Annually for 2 yr (spring) Early post: Annually years 1-3 (spring) Late post: Once every 3 yr (spring)
Q16. Does the presence and abundance of select fish species change due to modified stage-0 stream habitat and BDA installation?	Fish abundance declines initially in the shallow stage zero channel but increases as the stream network and beaver dam ponds develop.	Lamprey and eulachon presence and abundance	Electroshocking (lamprey); eDNA analysis of water samples (both species) §4.17	Pre: Once (lamprey, late summer) Early post: Annually (lamprey Aug, eulachon Feb) Late post: Annually (lamprey Aug, eulachon Feb)
		Presence and spawning evidence of coho	Spawning surveys; eDNA §4.17	Pre: Once (winter) Early post: Annually (winter) Late post: Once every 5 yr (winter)
Q17. Does wildlife use of Wasson Valley change with modified stage-0 restoration?	Wildlife use shifts from high ungulate use to species associated with beaver habitat (e.g., waterfowl). Use will increase after channel hydrology and woody riparian vegetation evolves.	Wildlife species ID, number and spatial extent of detections	Wildlife camera traps §4.19	Pre: 1 yr (continuous) Early post: In years 1, 3, and 5 Late post: Once every 5 yr
Q18. Does deer abundance in conifer forest change following forest thinning treatments?	Deer abundance increases as forest understory vegetation increases and diversifies.	Deer frequency of occurrence	DNA analysis from deer scat §4.19	Pre: 1 yr (spring) Early & late post: none
			Wildlife cameras during peak diurnal period §4.19	Pre: 1 yr (winter/spring) Early post: In years 1 and 5 (winter/spring) Late post: In year 10 (winter/spring)
Q19. Does wildlife species composition and frequency of use differ between forest prescriptions and by stand age?	Increased growth of understory vegetation in forest gaps and thinned forests lead to greater time spent in these habitat types compared to un-cut (skips and unmanaged) areas.	Species and frequency of occurrence	Wildlife cameras §4.19	Pre: 1 yr (winter/spring) Early post: In years 1 and 5 (winter/spring) Late post: In year 10 (winter/spring)
Q20. Does marbled murrelet habitat and use increase following forest prescriptions?	Nest habitat and use increase after approximately 10-20 years following prescriptions.	Relative tree platform abundance	Modified FIA plots §4.15	Pre: Once (FIA), 2 yr (murrelet) Early post: None Late post: Every 10 yr
		Bird presence in Wasson	Murrelet detection surveys §4.15	
Q21. Does a modified stage-0 restoration affect mosquito abundance in Wasson Valley?	Restoration will not significantly affect mosquito abundance.	Number of mosquitoes	Mosquito light/CO_2 traps §4.20	Pre: 1-3 yr surveyed (dry season) Early post: Annually until year 5 (fortnightly June - Aug) Late post: Every 5 yr (dry season)
Q22. Do forest thinning treatments affect salamander abundance and diversity?	Tree removal reduces salamander abundance and diversity, which are positively correlated with humidity and plant cover.	Number and diversity of salamanders	Salamander coverboard surveys in forest plots §4.21	Pre: 6 months Early post: Monthly for 5 yr Late post: Every 6 months

3. General monitoring approach and timeline

3.1 Monitoring design

Most of the restoration monitoring outlined in this plan follows a modified "before-after control-impact paired series" (BACIPS) design (Stewart-Oaten et al. 1986, Thiault et al. 2017). In the BACIPS framework, both restored and reference sites are monitored multiple times prior to, and following, an intervention or disturbance (restoration activities in this case). Due to the large scale and multiple ecosystem types present in this watershed restoration project, several types of reference sites are included in the planned monitoring. These multiple reference sites represent different possible restoration outcomes for the five zones within the project, including tidal marsh and swamp (potential late successional ecosystem types in WZ1), riparian and non-tidal freshwater emergent marsh (anticipated ecosystem types in WZ2, WZ3, and WZ4), and late seral coniferous forest (WZ5). The four zones in the Wasson lowlands also have pre-restoration differences in elevation, hydrology, and vegetation, and will undergo different types of restoration actions. A similar monitoring approach was used recently in the Southern Flow Corridor restoration project in the Tillamook Estuary where different zones at the restoration site had different land-use histories and two types of reference wetlands were monitored (Janousek et al. 2021a).

In addition to BACIPS monitoring, this restoration project will include five experiments in which randomized and independent replication of treatments and controls are incorporated into research designs. These include a biochar experiment, upland forest thinning experiment, tidal swamp nurse crib experiment, and experiments testing wetland woody species effects on reed canarygrass. These experiments involve more standard experimental design and have no associated pre-restoration monitoring. In several of the experiments, the outcomes of treatments will be assessed with repeated sampling over time.

Monitoring will be conducted by SSNERR staff and contracted partners ("monitoring team") with experience in monitoring methodologies, data management, and data analyses. The monitoring team consists of ecologists at SSNERR, Oregon State University, Oregon Department of Fish and Wildlife (ODFW), Coos Watershed Association, and Coquille Watershed Association, with additional technical expertise provided by staff from the Bureau of Land Management, Institute for Applied Ecology, USFS, US Fish and Wildlife Service, Coquille Indian Tribe, and the Confederated Tribes of the Coos Lower Umpqua and Siuslaw Indians. Monitoring protocols will follow this monitoring plan, but may be adapted due to unanticipated conditions, changes in funding or staff capacity, or development of improved procedures. Where improved or changed procedures are implemented, every effort will be made to make the old and new methods comparable (e.g., run both methods simultaneously and look for conversion factors). Since funding for monitoring beyond two to three years post-restoration has not yet been secured as of the time of this document's completion, long-term monitoring will be subject to the future availability of resources.

3.2 Restoration implementation and monitoring timeline

There are four restoration implementation and monitoring phases in the project: 1) pre-restoration monitoring, 2) project implementation, 3) early post-restoration monitoring and adaptive management, and 4) long-term monitoring and stewardship. A description of each phase and its associated timeline is given below.

Pre-restoration Monitoring Phase

Timeframe: prior to dates listed in implementation phase

Activities: Pre-restoration monitoring for zones WZ1-WZ4 involved new sampling from 2017 to summer 2024 as well as use of previously collected baseline data (mostly in reference sites as part of NERR Sentinel Site monitoring and other research projects). Pre-restoration monitoring in WZ5 started in 2011, with increased efforts in 2021-2024.

Restoration Implementation Phase

Timeframe: July-August 2024 for WZ1 & WZ2; August 2023 instream BDAs in WZ1; and April-May 2022, March-April and October 2025 for WZ5.

Activities: Intensive lowlands restoration actions were implemented during the summer of 2024, including fill of Wasson Creek and a linear ditch present on the north side of WZ1, grading the valley to a 1% grade line, excavation of a shallow sinuous pilot channel in the center of the valley as part of the modified stage-0 design, placement of LWD, and removal of RCG from areas of WZ1 and WZ2 in Wasson Valley (Table 6). Smaller scale restoration implementation actions included addition of BDAs in WZ1 in August 2023 to increase accretion within the stream. In WZ5, forest treatments included variable density thinning starting in the youngest stands in April 2022 and continuing with mid-aged stands in spring 2025 and oldest stands in fall of 2025.

Early Post-restoration Monitoring and Adaptive Management Phase

Timeframe: 28 August 2024 - summer 2027

Activities: Restoration implementation will be followed by a period of early post-restoration monitoring and adaptive management efforts (defined here as the first five years after implementation actions). During this period, potential additional actions will be identified and implemented to ensure success of the restoration project. These may include BDA maintenance and additional BDA construction (in WZ4), installation of brush and small wood pieces to slow and divert flow in WZ2, planting woody species, spreading native seed, removing invasive plants, pinning large wood pieces to limit their movement, constructing nurse log cribs (WZ1), applying biochar in high nutrient areas, and other unanticipated actions. Two experiments to guide adaptive management include a shrub planting trial in November 2022 and biochar trial in December 2024.

Early post-restoration monitoring in zones WZ1-4 will start between fall 2024 and fall 2025 following the completion of intensive restoration implementation in Wasson lowlands (some monitoring of woody species plantings in WZ4 was conducted in fall of 2023). Early post-restoration monitoring will encompass the first five years of site development (late 2024 to summer 2029). During this period, we will collect data on ecological parameters at different sampling frequencies, described in more detail in section 4 which details specific methodologies and in Tables 3-5. Some parameters will be evaluated annually during the early pre-restoration period similar to recommendations by CoqWA et al. (2024).

Long-term Monitoring and Stewardship Phase

Timeframe: Summer 2027 - ongoing

Activities: Long-term post-restoration monitoring and on-going stewardship of the project will begin in fall 2029. Anticipated stewardship actions will be conducted as needed and may include invasive species removal, thinning of densely planted young riparian trees, care and harvest of culturally important plants, and repair or replacement of nurse log cribs. Riparian plants were planted at high densities to account for herbivory and to increase competition with RCG. As needed, future thinning of these plants will be conducted if high plant densities appear to be leading to poor plant health.

Long-term monitoring is recommended starting in year six following the main restoration actions (2029) and extending to at least 20 years post-restoration. While our recommended monitoring frequency for many parameters decreases after the early post-restoration monitoring period, a long-term sustained effort to systematically collect data will lead to a more thorough understanding of ecosystem development. Continued long-term monitoring will also facilitate future adaptive management decisions including whether specific interventions may be needed to address unexpected problems. Other tidal wetland researchers emphasize the value of long-term monitoring for coastal restoration projects since restoration objectives tend to focus on shifting a degraded system to an alternative stable state that provides consistent long-term benefits (Callaway 2005, Roegner et al. 2009). Additionally, some desired outcomes in terms of habitat structure and function may take decades to reach (e.g. nesting habitat for marbled murrelet, evolution of stream networks, and development of tidal swamp vegetation).

Table 6. General timeline of restoration implementation and monitoring in the Wasson Valley Restoration Project.

Time period	Implementation action(s) and location(s)	Monitoring action(s) and location(s)
2004-2022	None.	Conduct pre-restoration monitoring of hydrology, soils, vegetation, and wildlife (WZ1-5, reference sites).
Spring 2022	Thin young stands in forest management units (FMU) 4-6 of WZ5.	Conduct pre- and post-implementation monitoring of nine forest plots, in FMU 4-6 (WZ5).
Fall 2022	Conduct pilot shrub planting in Wasson Valley (WZ4).	Implement annual willow survivorship survey following planting (WZ4).
Summer 2023	Install first set of beaver dam analogs (BDA) in lower Wasson Creek (WZ1).	Evaluate BDA elevation and height, stream flow velocity, channel morphology, and water temperatures (WZ1, WZ3, Anderson Creek reference site).
Summer 2024	Install additional BDAs in Wasson Creek (WZ1 and WZ3). Apply major Wasson Valley restoration actions including ditch filling, valley bottom grading, reed canarygrass removal, pilot channel excavation for fish passage (WZ1 and WZ2), large wood placement (WZ1-2), and addition of wildlife snags (WZ2). Improve the road in the upland forest (WZ5).	Conduct pre-and early post-restoration of groundwater monitoring in reference sites and WZ3, stream temperature (WZ1-4 and reference sites), and wildlife use (WZ1-3 and reference sites). Monitoring in WZ2 and most of WZ1 stopped during earth-moving activities.
Fall-Winter 2024-2025	Plant shrub stakes and add seeds of herbaceous species (WZ1-3), construct plant nurse cribs (WZ1), seed native understory in Forest Focus Plots, install brush diversions (WZ2), spread biochar in experimental plots (WZ1), and implement adaptive management actions, as needed (WZ1-5).	Re-establish monitoring infrastructure in disturbed areas (WZ1-2) and begin early post-restoration monitoring in WZ1-5 and reference sites including hydrology (WZ1-4), stream temperature (WZ1-4), wildlife use (WZ1-3,5), stream flow (WZ3), channel morphology (WZ1-3), wetland elevation (WZ1-3), water quality (WZ1), soil temperature (WZ1-4), and accretion (WZ1-2).
Spring 2025	Apply forest thinning treatments in mid-aged stands (FMU 2, 3, 7, 9, 10, 11 in WZ5), construct and plant additional nurse cribs (WZ1), apply biochar (WZ1), begin implementation of adaptive management actions as needed (WZ1-5).	Conduct early post-restoration monitoring in WZ1-5 and reference sites including benthic macroinvertebrates (WZ2), beaver activity and BDA surveys (WZ1-4), hydrology (WZ1-4), stream temperature (WZ1-4), wildlife use (WZ1-3,5), stream flow (WZ3), channel morphology (WZ1-3), wetland elevation (WZ1-3), water quality and nutrients (WZ1), and accretion (WZ1-2). Conduct pre-implementation monitoring of 21 forest plots in FMU 1-3, 9, 11, and 14-20 (WZ5), and at Dalton, Winchester, and Anderson reference forests.
Summer 2025	Install second set of BDAs in upper Wasson Creek as needed (WZ3) and implement adaptive management actions as needed (WZ1-5).	Implement early post-restoration monitoring in WZ1-5 and reference sites including emergent vegetation (WZ1-4), microclimate (WZ5), riparian cover (WZ1-4), mosquito abundance (WZ1), nurse crib moisture (WZ1), and greenhouse gas fluxes (WZ1-2). Continue early post-restoration monitoring of hydrology (WZ1-4), stream temperature (WZ1-4), wildlife use (WZ1-3,5), stream flow (WZ3), channel morphology (WZ1-3), wetland elevation (WZ1-3), water quality and nutrients (WZ1), and soil temperature and accretion (WZ1-2) in WZ1-5 and reference sites.
Fall 2025	Apply forest thinning treatments of older stands (FMU 14-17 and 19-20 in WZ5), create biochar from slash associated with forest thinning and spread in biochar plots, and implement adaptive management actions as needed (WZ1-5).	Continue early post-restoration monitoring of hydrology, stream temperature, wildlife use, stream flow, channel morphology, wetland elevation, water quality, water nutrients, soil temperature, sediment accretion, greenhouse gas fluxes (WZ1-2,), woody plant survivorship in nurse cribs (WZ1), and fish use (WZ3-4) in Wasson Valley and reference sites.
Winter 2025-2026	Continue woody plantings (WZ1-4), add supplemental shrub stakes and seed herbaceous species (WZ2), continue upland thinning treatment (WZ5), and implement adaptive management actions as needed (WZ1-5).	
2026-2029	Continue supplemental plantings and adaptive management as needed (WZ1-5).	
2029-2044	Implement adaptive management actions, as needed (WZ1-5).	Conduct long-term post-restoration monitoring in WZ1-5 and reference sites.

4. Methods by ecological parameter

4.01. Elevation

Elevation data with high precision and accuracy (<10 cm error) is important in wetland ecosystems (especially estuaries), because relatively small differences in elevation on the scale of a few decimeters can correspond with large differences in surface inundation or groundwater levels, affecting plant communities and other organisms (Janousek et al. 2019). High precision vertical data is also needed to track change in channel morphology. Additionally, in WZ2, one of the major implementation activities in summer 2024 was mechanical scraping of RCG dominated areas which is anticipated to lower surface elevation across much of this zone.

Three methods can be used to measure wetland surface elevation with high vertical accuracy and precision: high-precision global satellite system (GNSS) surveys, leveling, and remotely sensed Light Detection and Ranging (LIDAR) measurements. For routine wetland surface elevation surveys, and for determining the elevation of other monitoring infrastructure, real-time kinematic GNSS (RTK-GNSS) will be primarily used in this project (Figure 3). The method requires a field rover (GNSS receiver on top of a fiberglass pole) and connection to either a virtual or physical base station. In Oregon, with use of the Oregon Real-time GNSS Network (ORGN), RTK-GNSS has a fast set-up, but it is only effective in areas with relatively open sky since moderate to heavy tree cover blocks GNSS satellite signals. As of 2024, the Verizon carrier network typically has coverage in Wasson Valley and along Winchester Creek, enabling a dial-in connection to the ORGN at most sites in the project. When connecting to the ORGN, the recommended mount point is “iMAX_GG_RTCM3” because this enables use of additional satellites operated by other nations in addition to US satellites. Other mount points may also give adequate data but may provide less satellites which could make measurements difficult if nearby trees block some of the sky.

Figure 3. Field methods to determine elevation. At left, surveying with an RTK-GNSS rover, and at right, using a Sprinter level.

Measurement duration with RTK-GNSS in the field may vary depending on the type of measurement and the level of precision and accuracy needed. We recommend a minimum of 10 seconds for general topographic measurements such as the wetland ground surface or channel cross-sections. Where greater accuracy is particularly important (e.g., at groundwater stations), we recommend both longer measurements and multiple measurements at different times of the day or on different days under varying satellite configurations. For example, over the course of monitoring, the height of a groundwater well could be measured 4-6 times and these values would then be averaged.

Leveling is often the only option for determining elevation in tidal swamps because significant tree cover blocks satellite signals and makes GNSS use untenable (Figure 3). Leveling should be conducted from a nearby permanent or semi-permanent benchmark. One semi-permanent benchmark (a 2-m deep rod) was previously set up in the Winchester marsh area for leveling into the Winchester swamp. Best practices for leveling in the field include limiting use for distances under 100 m, not measuring during the heat of the day (heat waves cause lower accuracy), balancing fore-site and back-site distances as much as possible, avoiding measuring directly on a break in the extendable barcode rod, and not leveling across water (Schomaker and Berry 1981). Surveyors should also close the survey by returning to the original benchmark to assess misclosure tolerance.

Vertical control marks (hereafter "benchmarks") serve as points of reference to check RTK-GNSS measurement precision and accuracy and for leveling. Elevation measurements by RTK-GNSS in the field should be accompanied by periodic checks with the rover and virtual base station at benchmarks (Table 7; Figure 4). These checks enable evaluation of measurement accuracy (how close new measurements are to more formal elevation surveying) and precision (how repeatable measurements are over time). Several benchmarks were established prior to the start of the Wasson project (Table 7). As needed, additional benchmarks will be installed near study sites. Newly installed benchmarks will consist of stainless-steel rods, driven to refusal (typically 9-12 m deep in soft-sediment estuarine environments) following the approach in Cahoon et al. (2002). New benchmarks should be located in strategic locations that have open sky coverage (for GNSS measurements) and a good line of sight (for leveling) to monitoring infrastructure.

Once established, reference elevations for benchmarks are determined by static dual-frequency GNSS occupations (≥4 hours) which yield about 1 cm to 2 cm accuracies, or by leveling or simultaneous GPS surveys (which yield sub-centimeter accuracies). Simultaneous surveys should be collected at all project benchmarks and at least one tidal benchmark. A minimum of two occupations should be collected at each benchmark, in different combinations across multiple days. Following data collection, all data should be brought into the NGS OPUS Projects and corrected with a minimum of three nearby CORS stations and one distant CORS station (established at least five years ago). Simultaneous occupations should be completed for initial benchmark establishment, and again every 3 to 5 years unless there is evidence of movement in one or more benchmarks.

Table 7. Benchmarks present in the Wasson project, including permanent ID (PID) or other identification, published (or internally measured) northing and easting position (in UTM coordinates), and elevation (in NAVD88). Orthometric heights were calculated using the GEOID18 model. All benchmarks listed are on the map in Figure 4, except OA0651 which is in Charleston, north of the mapped area.

PID	Other stamping and description	Northing (m)	Easting (m)	Elevation (m)	Data source(s)
OA0651	Tidal 9, historic tidal benchmark associated with the NOAA Charleston tide gauge near OIMB	4799923.221 (A)	392397.296 (A)	4.849 (B) 4.859 (A)	(A) Average of 5 OSU RTK-GNSS measurements, 2023 (B) National Geodetic Survey leveling
NA	TOC, deep-rod benchmark in Toms Creek marsh installed in 2019	4792666.536 (A) 4792666.511 (B)	393156.724 (A) 393156.722 (B)	2.258 (A) 2.237 (B)	(A) One OSU RTK-GNSS measurement, 2023 (B) Network adjustment from multiple simultaneous GNSS static surveys, 2023
NA	WIN-BM, semi-deep rod benchmark in Winchester marsh installed in 2021	4791593.435	392773.637	2.531	(A) Average of 10 OSU RTK-GNSS measurements, 2023
NA	WM 4-1, deep-rod RSET benchmark installed in 2018	4791564.176	392752.124	2.684	Network adjustment from multiple simultaneous GNSS static surveys, 2021
NA	WZ1, deep-rod benchmark installed in 2023	4791758.107	392815.253	2.662	Network adjustment from multiple simultaneous GNSS static surveys, 2023
NA	WZ3, deep-rod benchmark installed in 2023	4792044.479	391925.984	10.574	Network adjustment from multiple simultaneous GNSS static surveys, 2023
NA	FS 4-1, deep-rod RSET benchmark installed in 2011	4791947.764	392966.189	2.741	Network adjustment from multiple simultaneous GNSS static surveys, 2021

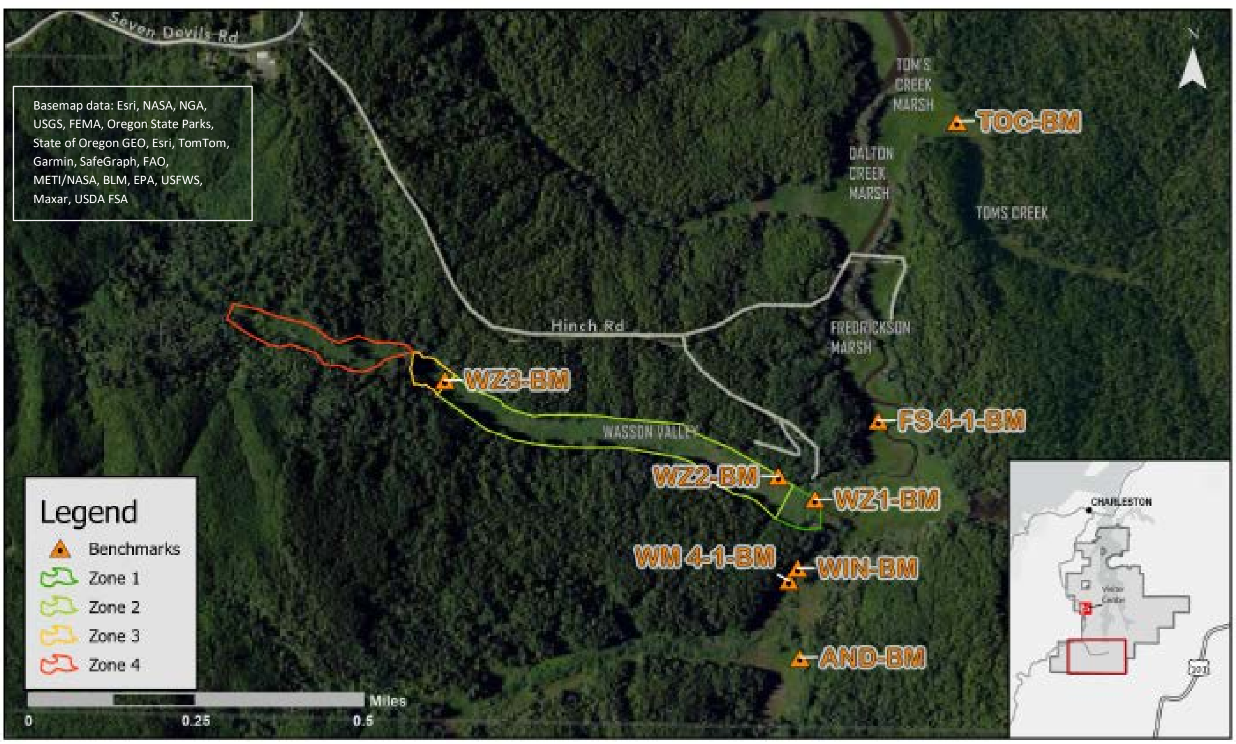

Figure 4. Map showing the location of semi-permanent (WIN-BM) and permanent deep rod (all others) benchmarks in the vicinity of Wasson Creek.

4.02. Surface and groundwater water level

In both tidal and non-tidal freshwater wetlands, surface and groundwater hydrology are key controlling factors of ecosystem structure and function (Ursino et al. 2004, Temmerman et al. 2005). Surface inundation in PNW estuaries is primarily tidally-driven (with two high and two low tides per day), but it is also impacted by changes in freshwater runoff from coastal watersheds (Brophy et al. 2011). In the project area, Winchester Creek is the main tidal waterbody, fed by sub-watersheds including Wasson Creek, Anderson Creek, and Tom's Creek. Groundwater is another important hydrologic factor in both tidal and non-tidal areas of the project. In tidal areas, groundwater varies daily (driven by tides and evapotranspiration by plants), monthly (affected by spring and neap tide cycles), and seasonally (influenced by precipitation) (Brophy and van de Wetering 2012, Janousek et al. 2021b).

At one or more stations in Winchester Creek, we will measure tidal channel surface water levels to determine patterns of surface water inundation in tidal reference sites and in the lower elevation areas of Wasson Valley. We will collect time series at each station with automated pressure sensors inside stilling wells (e.g., Hobo U20 and Aquatroll 200 data loggers). Loggers will record water levels at least every 30 min, but more frequent measurements (6 min as per NOAA tide station protocols) may be desirable. To correct raw water level data, a separate logger located above the highest possible water level (e.g., on a tree limb) will be used to obtain a concurrent time series of barometric pressure, with which the water level file is barometrically corrected in software (e.g., Hoboware, Win-Situ software, or using an R script). Alternatively, pressure data collected from the SOSTSMET can be used.

In Wasson lowland areas (WZ1-4) and tidal and non-tidal reference wetlands, we will monitor changes in groundwater levels (water table depth) in shallow groundwater wells (Figure 5). We located wells with Wasson Valley using a stratified random sampling approach. Wells extend up to 2 m below the ground surface and generally follow the design in Sprecher (2000). Briefly, wells consist of a subsurface PVC pipe with perforations to let water circulate into and out of the well and an above-ground portion (riser) which is solid PVC and therefore does not allow exchange of water inside the well with surface water (e.g., at high tide). Soil at the base of the well is amended with bentonite clay which helps provide a water-tight seal.

We will add pressure sensors to the wells to obtain time series of groundwater levels. The distance between the pressure sensor position on the data logger and the ground surface will be carefully measured so that all water level values can be computed relative to the ground surface. If a groundwater well has a high chance of fine sediment accumulation over time, it should be periodically pumped out to remove sediment, or the logger can be suspended a few centimeters above the bottom of the well suspended on a non-stretching line. Loggers collect measurements every six hours in non-tidal areas (where groundwater is expected to change slowly), and every 30 minutes in tidal areas which tend to have more dynamic groundwater conditions due to tidal influence. Data on sensors will be downloaded

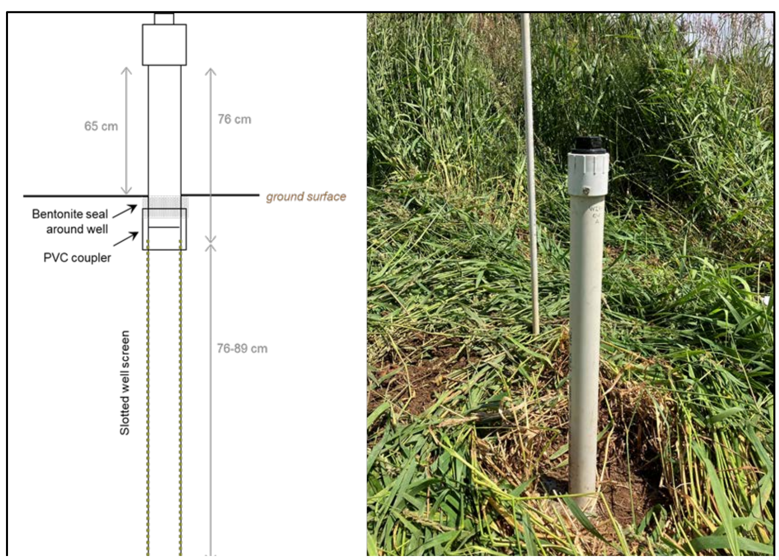

Figure 5. Monitoring of groundwater in tidal wetland and riparian areas. At left, schematic of a groundwater monitoring well. At right, a newly installed well in WZ1 in June 2023.

approximately every few months before memory fills and to ensure that loggers are still functioning as expected.

The elevation of the top of the well's riser and the ground surface adjacent to the well will be measured by RTK-GNSS or leveling methods (see section 4.01). In addition, groundwater conditions (temperature and salinity) will be periodically measured independently with a hand-held water quality meter (e.g., YSI Pro 30 or Pro 1030), or a refractometer at the time that data loggers are downloaded. To obtain accurate water level time series for groundwater, it is necessary to correct raw pressure data with a time series of barometric pressure as described above for channel loggers.

4.03. Tidal channel, groundwater, and stream water quality

In tidal areas (Winchester Creek hydrology station(s), and groundwater wells in tidal sites), we will also monitor channel and groundwater salinity. Salinity time series will be obtained with Odyssey or Aquatroll 200 conductivity loggers. Aquatroll 200 loggers (sensor accuracy ± 0.5% of reading) are downloaded and calibrated for conductivity at least every three months. Odyssey loggers (sensor accuracy ± 3% of reading) record specific conductance, which is then converted to salinity using the equation in Wagner (2006). Odyssey loggers cannot be calibrated by the user, however specific conductance readings of are checked in the lab under controlled conditions across a range of salinities and can be corrected for deviations from independent measurements. Both logger types (as well as Hobo loggers used to measure pressure) also record groundwater temperature. Loggers are downloaded periodically and channel or groundwater salinity is measured independently at the time of logger downloads with handheld YSI meters.

We will monitor stream temperatures at stations above and below each Wasson Valley treatment zone, as well as in reference site creeks (Tom's Creek, Winchester Creek, and Anderson Creek) using HOBO MX2201 pendant loggers (Figure 6). The loggers are mounted onto a silicone boot attached to a rebar post and positioned approximately 10 cm above the bottom of the creek to avoid burial by sediment. Loggers will collect temperature data at 15 minute intervals. We will download them at least twice per year and check for stream dewatering or sediment burial as well as battery condition.

Figure 6. Example of stream temperature monitoring. The temperature sensor is located approximately 10 cm above the creek bed.

We will monitor channel water quality more extensively in three locations along Winchester Creek. We will deploy a YSI EXO2 multiparameter sonde at the lower boundary of WZ1 near the confluence of lower Wasson Creek with Winchester Creek (43.2706°N, 124.3207°W) to measure turbidity, specific conductivity, temperature, dissolved oxygen, and pH changes in this region of the estuary due to restoration activities. We will also deploy a second sonde upstream near the upper extent of tidal influence on the main stem Winchester Creek (43.2674°N, 124.3210°W). Finally, we will use data from the downstream Winchester Creek long-term SWMP station (43.2825°N, 124.3203°W) that routinely collects water quality parameters. Sondes will include sensors for dissolved oxygen, temperature, conductivity, and turbidity and will be programmed to continuously collect data every 15 minutes. Sondes will be swapped out quarterly to download data and clean and recalibrate sensors following NOAA NERRS (2023) protocols.

To determine nutrient concentrations in tidal channels, we will collect water samples monthly, on the same dates that stream flow rate data are collected (see section 4.05 below). We will obtain water samples before or during slack low tide near the mouth of Wasson Creek (43.2705°N, 124.3209°W) and in Winchester Creek just upstream of the mouth of Anderson Creek (43.2681°N, 124.3205°W). Following NOAA NERRS (2023) protocols, we will collect three replicates of surface water in amber or opaque 1 liter containers that have been acid washed prior to sample collection. Samples will be kept cool while in the field and then filtered immediately upon return. Filtered samples will be preserved by storing them at -20^{o} C. Samples will then be shipped overnight to an analytical lab for analysis.

4.04. Tidal channel and stream morphology

Tidal and riparian channels are critical conduits of water, salt, tidal and fluvial energy, and biota in estuarine ecosystems (Hood 2020). These drainage networks naturally evolve over long time scales. Wasson Creek was dramatically impacted by human activities during the 20th century which altered its course within Wasson Valley. Moreover, the stage-0 restoration in this project implemented during summer 2024 highly modified the stream network yet again. Tracking changes to stream morphology will help our team document the evolution of hydrology in Wasson Valley in response to these restoration actions (e.g., stage-0 and pilot channel development, or effects from BDA installations).

To assess geomorphological changes, we will conduct post-restoration channel morphology measurements in WZ1-3 to obtain data on channel depth, channel cross-sectional area, channel depth to width ratio, anabranching index (Ai), and channel density. We will collect channel and stream morphology data both by remote sensing and field measurements.

We will use un-crewed aerial vehicle (UAV) flights to determine stream flow pathways in Wasson Valley (channel density and Ai) from aerial multispectral imagery and LIDAR elevation data (Scott 2024). We will conduct UAV flights immediately following restoration and twice annually thereafter during both peak winter flow and the summer dry season (until vegetation growth near channels is too dense to use this method). To reduce visible shadows on the imagery, we will schedule flights between 10 AM and 12 PM. We will equip UAV flights with a combination thermal infrared (TIR)/multispectral sensor (see section 4.07.2 for more details). We will count channels that have a width of at least 0.6 m. Due to valley regrading activities in summer 2024 and loss of elevation in WZ1 and lower WZ2, we will also use LIDAR and Elevation-Based Estuary Extent Model (EBEEM) methods to extent of tidal influence following restoration (Brophy et al. 2019). We will determine the new 50% exceedance boundary (i.e., wetland area that is tidally influenced at least once every two years) using a LIDAR-derived digital elevation surface model.

To determine channel width, depth, width-to-depth ratio, and channel cross-sectional area, we will collect on-the-ground measurements of channel thalwegs (lowest points) and cross-sections with RTN-GNSS or RTK-GNSS methods. Prior to restoration, we measured the location and depth of the thalweg at points spaced every few meters along Wasson Creek in WZ1 and WZ2. At this time we also conducted channel cross section measurements at intervals of approximately 15-20 m (WZ1 and WZ3) or 50 m (WZ2) along Wasson Creek. Each individual cross-section consisted of elevation measurements spaced approximately 10 cm across a stream segment from the top of one bank to the opposite bank.

Following restoration, we will measure changes to the channel thalweg location and depth and to channel cross sectional area. Similar to pre-restoration monitoring, starting in the first year following restoration, we will conduct channel thalweg measurements at regular intervals (2 m to 5 m in WZ1 and

WZ3; 10 m to 20 m in WZ2) along the length of the pilot channel constructed in summer 2024. In sections of streams that have braided channels, we will follow the largest branch.

Due to substantial changes in channel morphology associated with stage-0 restoration in WZ1 and WZ2, we will use modified methods for channel cross-section measurements after restoration. We will measure cross sections across the entire width of the valley starting and ending above floodplain level. We will co-locate these stream morphology transects with groundwater and vegetation monitoring transects (sections 4.02 and 4.13.1). At each transect (n = 10 in restored Wasson Valley, and n = 6 in reference TOC), we will conduct elevation measurements at 2 m intervals (Figure 7). When a defined channel is reached (i.e., where the water is confined by banks on both sides), we will take measurements perpendicular to the channel edge about every 20 cm from the top of one bank to the top of the subsequent bank (which may deviate from transect bearing). We will then return to the first bank and continue collecting data at 2 m intervals along the transect. In the event the same channel is intercepted along the transect line, we will only resume cross-section measurements at least 20 m away from the first crossing. We will code each point collected either as: Dry.Veg (>50% vegetation cover that is generally dry in high flow events), Dry.Unveg (<50% vegetation cover that is generally dry in high flow events), Wet.Veg (>50% vegetation cover that is generally inundated in high flow events), or Wet.Unveg (<50% vegetation cover that is generally inundated during high flow events). Since WZ1 is tidally influenced post-restoration, we will conduct measurements in that zone during low tide. Other monitoring related to channel morphology includes stream flow velocity measurements 4.05 and aquatic habitat composition (sections 4.05 and 4.06 below).

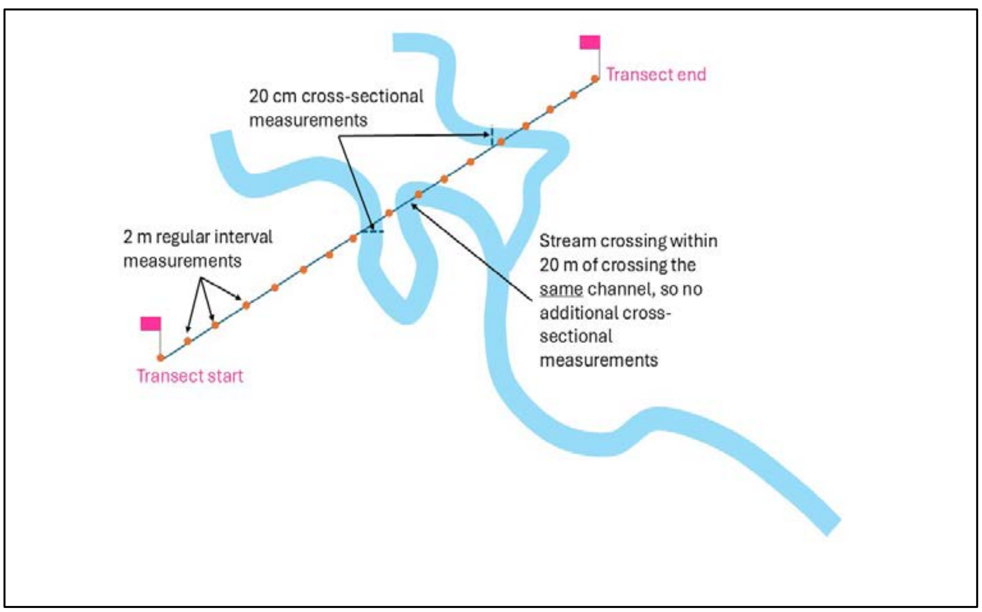

Figure 7. Schematic illustrating modified post-restoration methods for conducting channel morphology transect measurements that span the width of the valley.

4.05. Stream flow rates

BDAs are designed to mimic the function of natural dams by slowing surface water flow, allowing sediment retention behind the dam, and facilitating a developing stream to become wider and shallower (Pollock et al. 2014, Pollock et al. 2023). To quantify changes to stream flow velocity, we will measure velocity at five individual channel reaches within Wasson zones 1 and 3 (where BDA installation is focused) and in both tidal and non-tidal sections of Anderson Creek (reference site) with a current flow meter (Figure 8). At each channel reach, we will conduct velocity measurements at evenly spaced points spaced approximately 10 cm to 20 cm apart along a transect perpendicular to the channel bank, to obtain approximately 10 measurements per reach. Measurements will be taken about halfway between the water surface and the channel bottom at each interval. For each measurement, the flowmeter will average velocity for 30 seconds. As a best practice, observers should stand to the side and downstream of the flow meter during readings. Data will be collected several times during the dry season (likely June and October) and monthly during the wet season (November through May).

Figure 8. A surveyor measuring stream water velocity to quantify flow.

4.06. Habitat features

We will use UAV flights to collect data complementary to on-the-ground methods to track changes to other large-scale habitat features within zones 1-3 of Wasson Valley. These include large wood location, movement, and density; landscape-scale channel characteristics such as sinuosity and degree of branching (see section 4.04); and elevation change (Table 8). Elevation change analysis will consider changes to grade and microtopography (e.g., erosion or accretion of mounds, islands, or toe slopes over time). We will conduct UAV flights immediately following restoration and twice annually thereafter during both peak winter flow and during the summer dry season (until vegetation growth near channels is too dense to use this method). We will collect similar data annually in TOC and/or TOM if resources permit.

Table 8. Example habitat features that will be monitored in each zone of Wasson Valley during the early post-restoration period.

Habitat feature	**Description**
Active channel width	The bankfull width of the channel.
Large wood	Parameters include number of large wood pieces located in the stream, density per km of stream, single log versus log jam complexes, number of root wads, and movement over time.
Elevation changes	Changes to grade and microtopography.

4.07. Soil Temperature

4.07.1 - Subsurface temperature loggers

Soil temperature in Wasson Valley and nearby reference wetlands may be affected by seasonal changes in weather, extreme weather events, and changes in groundwater hydrology and vegetation cover associated with restoration. Temperature may impact biota and soil processes such as greenhouse gas emissions (Schultz et al. 2023).

We will collect time series of soil temperatures in each of the four Wasson Valley zones and in select reference wetlands (TOC, FSM, WIN-TS) by burying small data loggers 5 cm to 10 cm below the soil surface near groundwater wells (n = 2 per Wasson zone or reference site). A number of waterproof logger types with sufficient memory capacity can be used for this purpose. The loggers can be sealed in one or more small plastic bags to provide extra protection from water and to keep the logger surface clean. To deploy the loggers, a small spade or other tool is used to create a shallow hole, the logger is added, and soil around the hole is closed up. Logger locations relative to groundwater stations are carefully marked so that they can be easily found during subsequent visits to download data. Since sub-surface soil temperature does not change rapidly, we will program data loggers to record values every two hours. We will excavate, download, and replace batteries in loggers approximately every 6 to 12 months, and return them to their position underground.

We will process raw data by plotting temperature time series to search for outliers and by filling data gaps with "NA" values as needed. From these processed time series, we will calculate summary statistics on monthly, seasonal, and annual time scales for each station.

4.07.2 - Surface temperature using thermal imagery

As an additional method for determining surface soil temperature in Wasson lowlands, we will conduct UAV flights fitted with a TIR/multispectral sensor. This method will enable observation of spatial variability in temperature in detail across the entire valley. We will conduct flights once before restoration, soon after restoration, after the first wet season following restoration, and then twice annually in the spring and fall thereafter. We will conduct flights between 10 AM and 12 PM to reduce visible shadows on the imagery.

We will conduct UAV flights with a DJI Matric 300 RTK model airframe with a Micasense Altum PT sensor. Each mission will have 80% forward overlap and 70% side overlap to produce an orthomosaic from the imagery. The UAV will fly 150 m above ground level, resulting in a ground sampling distance (GSD) of no more than 1 cm for the thermal band. We will use ground control points that are measured with RTK-GNSS to georeference the orthomosaic. To calibrate the sensor to atmospheric site conditions on the day of flights, we will use digital temperature and humidity loggers located on the ground and that are mounted on the airframe. For rough evaluation of thermal imaging data, we will use independent temperature data from stream temperature loggers and near-surface soil loggers (sections 4.03 and 4.07.1). We will plan the flight paths in UGCS software, process imagery in Pix4D Mapper, and develop final products in ESRI ArcPro. We will analyze imagery to classify visible wetted area and radiant surface water temperatures during pre-and post-restoration periods, and temperature response after major winter flow events. We will use the visible wetted areas to help map the newly developing stream network in Wasson Valley (see section 4.04).

4.08. Soil characteristics

Wetlands are often sites of significant organic carbon and nitrogen accumulation and storage (Kauffman et al. 2020). Measurement of carbon accumulation rates (CAR) can help inform wetland function and management for climate regulation and carbon storage. An estimate of how much and how quickly carbon is accruing in wetland soils can be obtained by analyzing vertical profiles of soil cores.

We will determine soil bulk density, carbon and nitrogen density, and carbon accumulation rates in multiple Wasson Valley zones and in reference wetlands with soil cores collected to approximately 50 cm depth. The same core samples can typically be used to determine all of these properties using different analytical methods (analysis of soil core data to estimate CAR using radiometric dating is covered in section 4.09). Cores are obtained by sampling soil with a sharpened gouge auger or Russian peat borer and then sectioning the extracted core vertically into 2 cm subsections (Figure 9).

Initial sample processing involves determining dry bulk density (DBD) by thoroughly drying a known volume of wet soil at 60°C for several days and then weighing the sample. Next, sample organic matter content is determined on a subsample of the homogenized sample used to determine DBD. This subsample can be ashed in a muffle furnace by the loss-on-ignition (LOI) method to determine total organic matter content (Heiri et al. 2001), or run on an elemental analyzer to specifically determine carbon and nitrogen content. To quantify differences in soil characteristics by site, we will determine DBD and organic matter once during the pre-restoration period in reference wetlands (TOC, AND, FSM, WIN-EM and WIN-TS) and in WZ1 and WZ2 (minimum 2-3 cores per site). To assess long-term change in soil conditions, additional cores may be collected from WZ1 and WZ2 at least 10-20 years after restoration implementation when surface soils have had some time to develop.

Figure 9. Example soil core collection to determine soil characteristics including dry bulk density, carbon content, and accretion rate.

4.09. Sediment accretion rates

Vertical accretion is the rate at which sediments and organic matter are accumulating in a wetland to build up soils, a key metric for assessing carbon accumulation and elevation change. Accretion rates help in understanding how well a wetland can adapt to long-term sea-level rise, and for ensuring that restored sites have similar ecological functions as reference wetlands. Several methods are available for determination of vertical accretion rates. Methods vary in terms of cost and time scales over which they measure accretion.

Feldspar marker horizons are used in wetlands to measure shorter-term sediment accretion rates up to about 10 years, providing a low cost method (Cahoon and Turner 1989; Figure 10). This technique is inexpensive and can be replicated more easily than other methods. However, it requires that several years elapse between the establishment of marker horizons and their sampling. Feldspar layers are established by depositing a 5 mm to 10 mm thick layer of inert powdered feldspar clay to the wetland surface (e.g., in a 0.25 m^2 area). It is often necessary to thin the existing above-ground vegetation at the time of plot establishment in order to establish a more contiguous layer across the desired area; experience suggests that plant canopies can recover quickly from the biomass removal. The periphery of the plot is marked by posts of PVC or other materials so that the plot is not disturbed by foot traffic and can be located once the feldspar layer is covered with sediment and no longer visible. Several years after establishment, accretion is measured by collecting a small core within each plot and measuring sediment depth above the feldspar horizon to millimeter precision.

To monitor post-restoration accretion rates in Wasson Valley, we established replicate marker horizon plots in both restored and reference lowland sites in fall 2024. In WZ1, WZ2, and tidal reference sites, we established a minimum of six plots. Some plots were located in similar locations as pre-restoration plots while others were established randomly within a site or positioned near other monitoring infrastructure. If plots are disturbed early in the post-restoration period, we will replace them. Most plots will be located close to groundwater wells.

After the early post-restoration period, we will measure accretion in plots every additional two to three years. Additional plots can be established at later time points, especially if initial plots are damaged. Some pre-restoration measurements of accretion rates were obtained from WZ1, WZ2, WIN-TS, and FSM as part of a previous blue carbon study (Janousek, Williams, Bridgham, Cornu, unpublished data).

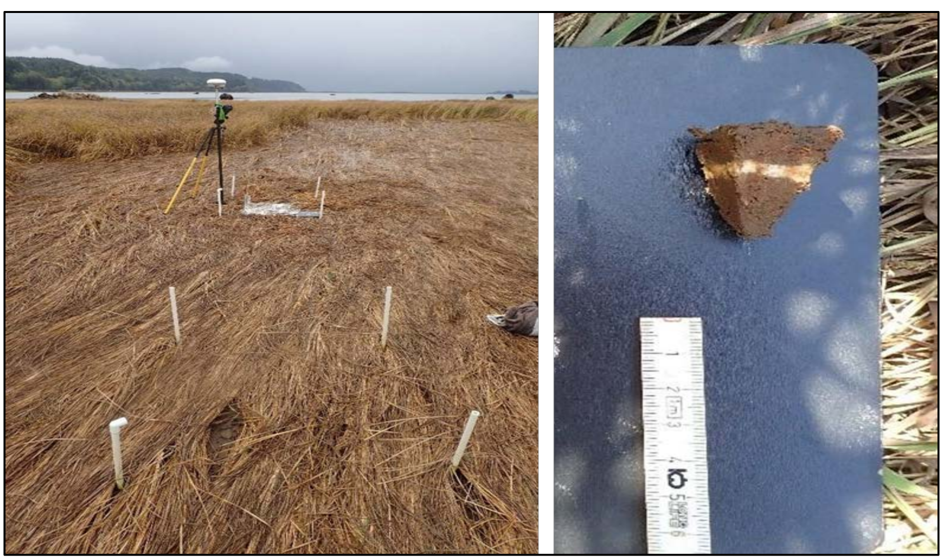

Figure 10. Examples of two feldspar marker horizon plots established in a tidal marsh in northern Oregon (at left) and a soil core collected from a marker horizon plot with a distinct sub-surface feldspar layer (at right).

For determining longer term rates of sediment accretion (e.g., on decadal to century time scales) radiometric dating of soil core profiles is often the method of choice. Two elements are typically measured in these profiles, ^{210}Pb and ^{137}Cs (Poppe and Rybczyk 2021). Quantitative cores are collected in the field as outlined in section 4.08 with a gouge auger or Russian peat borer and then sectioned vertically into 2 cm sub-samples (often the same cores can be used for determination of bulk density, carbon density, and radioisotope dating). Using a gamma detector in the lab, the activity levels of radionuclides in sub-samples are determined and vertical profiles are constructed (Drexler et al. 2018). From the vertical profiles, models are used to estimate the rate of sediment accumulation over time (Sanchez-Cabeza and Ruiz-Fernández 2012). For example, the depth of the peak concentration of ^{137}Cs corresponds to the year 1963 when there was maximum global deposition of atmospheric ^{137}Cs due to atomic weapons testing.

Radiometric dating is typically less successful in soils subject to disturbance. In addition to new soil cores collected as part of Wasson project monitoring, existing accretion rates from reference site accretion rates (FSM and WIN-TS) are available in the Northeast Pacific Blue Carbon Database from previous research (e.g., Brown et al. 2024, Poppe et al. 2024).

4.10. Greenhouse gas emissions

In addition to their carbon storage and sequestration benefits (Chmura et al. 2003, Kauffman et al. 2020), wetlands uptake and emit GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Both CH_4 and N_2O are potent GHGs which have a much higher global warming potential than CO_2 (Neubauer and Megonigal 2015). In tidal and non-tidal wetlands, fluxes of CH_4 and N_2O are affected by several environmental factors which have positive or negative effects on the soil microorganisms that produce these gasses, including but not limited to the availability of oxygen, soil substrates, energy sources, temperature, pH, and salinity (Stavert et al. 2022, Tian et al. 2020).

In previous research conducted by OSU in partnership with SSNERR, CO_2, CH_4 and N_2O fluxes from soils were determined in the southern region of SSNERR in 2021-2022 at FSM, WIN-TS, WZ1, and WZ2 with a portable gas analyzer (Williams et al. 2025). These data provide an important window into pre-restoration gas fluxes in Wasson Valley (mainly in areas dominated by RCG and with altered hydrology).

At the same four sites, we will conduct chamber-based measurements of CO_2 and CH_4 early in the post-restoration period (2025-2026) using the same methods as Williams et al. (2025). In brief, each site will consist of six PVC collars left partially embedded in the site's soils, short boardwalks to minimize ground disturbance during measurements, and a groundwater station for continuous measurement of water level and salinity. At periodic intervals (likely every 2-3 months) over the course of a year, we will sample GHG concentrations by placing a chamber over the collars and measuring the change during short incubations (~10 min) using a portable gas analyzer under light and dark conditions (Figure 11). We will determine fluxes by calculating the rate of change in concentration within the chamber.

Figure 11. A closed-loop chamber used to measure GHG concentrations in FSM.

We will compare GHG fluxes by season and site and between pre- versus post-restoration periods. Additionally, we will use the time series of environmental measurements and the machine learning model developed in Williams et al. (2025) to estimate annual methane emissions at each site. The pre- and post-restoration data will assist with estimation of radiative balance budgets, including in the lower Wasson Valley.

4.11. Upland microclimates

While forest thinning can reduce long-term wildland fire risks (Brodie et al. 2024), in the short-term thinning has the potential to increase fire suitable conditions, such as increased temperature and decreased humidity in the forest understory (through reduced canopy cover) if high fuel loads are also present following thinning. Therefore, we will monitor temperature and humidity before and after forest prescriptions during the dry months. We will measure microclimate conditions in each of the 12 Forest Focus Plots (section 4.14.4) inside a thermometer shelter (inside dimensions 23 cm width, 15 cm depth, 45 cm height) with the base 90 cm above ground surface (Figure 12). Each shelter faces south and contains one temperature/humidity logger (Extech RHT30) positioned 18 cm from the ceiling of the shelter, and programmed to collect data at 10 min intervals between June through December.

Figure 12. Thermometer shelter used to measure forest microclimate conditions.

4.12. Biochar experiments

After the Wasson restoration groundwork was completed in August 2024, we observed areas around the old barn at the north side of WZ1 where nutrient rich water was seeping through the soil and draining into the wetland. Therefore, we decided to experiment with biochar applications to reduce nutrient runoff to the valley (Haider et al. 2017). On 4 December 2024, we identified an area of seepage from the valley toe slope below the barn. Here we marked 14 circular plots (0.56 m radius, 1 m^2 area) with wooden stakes (Figure 13). Plot edges were at least 1 m from the edge of any adjacent plots. Each plot had visible surface water.

Prior to biochar application, we collected surface water samples (300 ml) from each plot with a large syringe in 1 liter Nalgene bottles. We kept samples in a cool location out of the sun and then refrigerated them upon return to the laboratory within 3 hours of collection. We filtered samples using Whatman GFF 934 AH filters into acid-washed 60 mL Nalgene bottles within 24 hr of collection and then froze them (-80°C) for storage until analysis.

After baseline water samples were collected, we applied the biochar treatments randomly to plots. Treatments included controls (no biochar) or biochar application (18.9 L m^{-2}). In biochar addition plots, we smoothed biochar by hand evenly across the plot, and pressed it into the soil with boots. At control sites, we smoothed and pressed soil without biochar. We will resample surface water in plots for determination of nutrient concentrations after 2 weeks, 1 mo, 2 mo, 3 mo, 6 mo, 12 mo, and 24 mo following biochar applications. Samples will be analyzed for nutrient concentrations including nitrite, nitrate, ammonium, and orthophosphate by the CTCLUSI analytical laboratory.

Figure 13. Setting up the lowlands biochar experiment in WZ1.

4.13. Emergent marsh vegetation

4.13.1 Field plots

Plants and benthic algae have important roles in wetland ecosystems including providing physical structure that traps sediments and is home to wildlife species, changing the soil environment, and fixing carbon for wetland food webs (Kwak and Zedler 1997, Cahoon et al. 2020). Vegetation in emergent marshes in the PNW includes benthic microalgae such as diatoms, macroalgae, graminoids (grasses, rushes and sedges), forbs, and occasionally some shrubs and small trees (woody vegetation in tidal swamps is covered in section 4.14). Commonly measured vegetation parameters in emergent marsh monitoring include percent cover, species composition (including non-native species abundance), and diversity (Brophy et al. 2014, Janousek et al. 2021a,b). These parameters are a key component of the Wetlands and Water Levels monitoring program across the NERR system (NOAA 2012, NOAA 2016).

In each Wasson lowland zone (WZ1-4) and most reference sites (TOC, FSM, WIN-EM, WIN-TS), we will monitor vegetation cover, composition, and species richness along four or more fixed transects. Transects are located near groundwater well locations (section 4.02) at most sites or were otherwise randomly assigned. Transects are positioned along a site's approximate elevation contour (e.g., parallel to a tidal channel in tidal sites or in a north-to-south orientation in Wasson Valley). Each transect contains five vegetation plots (1.0 m^2), evenly spaced from a random starting point (Figure 14).

At the time of sampling, we will determine percent cover of each plant species and macroalgal group using the point-intercept method from Roman et al. (2001) where a vertically-held 5 mm-diameter fiberglass rod is lowered through the plant canopy to the ground at each of 50 points in the quadrat. All plant species contacting the rod are recorded at each point and the total number of scores for a species are tallied and converted into percent cover (by multiplying total scores by a factor of two). To ensure that species present with low cover are also quantified, we will assign those species a cover estimate of 1% if they occur inside the plot. In addition to plants and macroalgae, we will also record other cover classes such as un-vegetated bare ground and unattached wrack.

At each plot, we recommend taking and archiving an orthogonal photograph of the vegetation present. While these photographs may not well capture plants below the upper-most canopy, they provide a good record of taller abundant species and can be reviewed at a later date if recorded data are uncertain. In addition, if any unknown species are encountered in the plot, a photograph and/or voucher specimen should be collected so that it can be identified. At the edge of each vegetation plot, we will measure wetland surface elevation by RTK-GNSS or leveling methods (see section 4.01). We may also measure soil pore water salinity at each plot by collecting a small sample of subsurface soil (e.g., 5 cm below the ground surface) with a spade or hand-auger, compressing the soil to extrude pore water (e.g., in a syringe fitted with filter paper), and reading pore water on a hand-held refractometer.

Figure 14. A field researcher using the point intercept method in a 1.0 m^2 plot to quantify vegetation cover by species.

4.13.2 Aerial imagery with UAVs

We will also use UAV methods to monitor vegetation prior to and following restoration at WZ1 and select reference sites (TOC and WIN-TS) to understand spatial and temporal development of woody and herbaceous species (e.g. RCG, Sitka spruce). For aerial imagery acquisition, processing, and analysis and ground-based vegetation surveys, we will follow methods by Puckett et al. (2022). Per these protocols, aerial surveys will utilize ground control points. Outputs will include spatial and temporal differences in normalized difference vegetation index (NDVI), un-vegetated-to-vegetated ratio (UVVR), and supervised classification of plant community types. We will aim to conduct imagery acquisition within one week of vegetation plot assessments along fixed transects (as outlined in section 4.13.1).

4.14. Woody vegetation success and development

4.14.1 Evaluation of riparian woody plantings (survivorship and growth)

In several Wasson Valley zones, restoration actions involve planting of woody vegetation to facilitate freshwater riparian and tidal swamp habitat development. In 2022, shrub stem cuttings were planted in 12 six-meter diameter plots in WZ4 to experimentally test how woody plantings may reduce RCG cover. Plots were randomly assigned to one of two density treatments (75 or 150 stems) and one of two species composition treatments: only willow (*Salix* spp.), or a mix of willow, red osier dogwood (*Cornus sericea*), Douglas spirea (*Spiraea douglasii*), twinberry (*Lonicera involucrata*), and Pacific ninebark (*Physocarpus capitatus*). We will assess survivorship of woody stem plantings annually by surveying each plot in early fall after RCG partly senesces but woody species still retain their leaves.

To quantify basal area and density of plantings, we will record stem diameters for all species after they grow to a minimum of 1.4 m (all stems below that height will simply be counted). We will measure single stems at 1.4 m above the ground. Following Peet et al. (1998), if there are multiple stems from the same root system, we will record them as separate stems if they branch at a height less than 0.5 m above ground. Multiple stems that branch between 0.5 m and 1.4 m aboveground will be measured at the narrowest point on the main stem below the branch. All woody stems greater than 4 m in height will be considered a tree and no longer counted as a shrub. Woody vegetation data will be compared with emergent vegetation data collected in the same zone to understand changes to RCG cover (see section 4.13.1 above).

4.14.2 Mapping of riparian species cover by UAV

At a larger scale, we will assess the aerial extent of woody vegetation in each lowland zone of Wasson Valley periodically by conducting periodic UAV flights equipped with LIDAR and multispectral sensors (Figure 15). Flights for vegetation mapping will occur during the peak growing season (late spring to summer). Once woody vegetation has reached a minimum height (2 m from first return LIDAR data), we will assess canopy cover, vegetation height, and potentially deciduous versus coniferous plant cover in surveyed polygons in GIS. Using data from repeated flights over time, we will determine temporal changes in vegetation metrics as Wasson Valley lowland vegetation communities develop.

In early post-restoration monitoring, we will conduct sampling in Wasson Valley during the peak wet and dry seasons for the first five years. Flights will be conducted between 10 AM and 12 PM to reduce visible shadows on the imagery. Flights are planned to occur once before restoration, directly after restoration, after the first major rain event, and then bi-annually in early summer (leaf-on) and late fall/winter (leaf-off) to capture vegetation conditions.

Figure 15. A field researcher conducting a UAS survey equipped with LIDAR and multispectral sensors at Toms Marsh.

When interpreting and analyzing both woody and emergent vegetation data it is important to note that early vegetation changes are likely to be driven by several factors simultaneously including management actions (e.g., active planting, native seed dispersal and invasive plant management), natural recruitment of propagules, and environmental modification (e.g., changes in hydrology and elevation). Early post-restoration vegetation monitoring occurs during the adaptive management stage and may therefore represent additional planting and weed removal activities conducted during the first two years of post-restoration development. Later post-restoration monitoring will quantify plant community change as the restoration site matures.

4.14.3 Experimental elevation treatments for tidal swamp species establishment

To facilitate establishment of woody species in tidal swamp restoration, methods such as establishment of elevated mounds or nurse cribs (or logs) may be helpful (Recht et al. 2024). Following the Wasson Valley restoration, we will conduct a nurse crib experiment in the tidally-influenced portion of the lower valley (WZ1) to test the effect of elevation on tidal swamp tree and shrub species survivorship and growth, particularly Sitka spruce (*Picea sitchensis*), Pacific crabapple (*Malus fusca*), and twinberry (*Lonicera involucrata*). The results of this experiment will provide important information about the optimal elevation range for woody species growth in future tidal swamp restoration projects as well as the structural integrity and longevity of various sizes and styles of log cribs. Nurse cribs are collections of approximately 5-20 cm diameter logs bound together to form an open central chamber that is filled with partially decomposed spruce wood chips (Figure 16). They mimic large fallen trees in a least-disturbed tidal wetland which can serve as nursery habitat for growth of young woody species.

In WZ1 we plan to install 25 nurse cribs, spaced about 7 m to 10 m apart based on tree spacing in the adjacent Winchester tidal swamp reference site. The tops of nurse cribs have a target elevation range of 2.4 m to 3.0 m NAVD88, which spans the full elevation range in the Winchester tidal swamp (2.35 m to 2.72 m, NAVD88) (Schmitt and Helms 2017). Since the post-restoration graded surface of

WZ1 ranges from 1.75 m to 2.5 m NAVD88, nurse crib heights will vary from 0.24 m to 1.1 m. Of the 25 cribs, we installed 13 on 1 February 2025. Five cribs were single chamber and eight were three tiered (Figure 16), resulting in 29 planting chambers. We installed an additional eight cribs on 18 April 2025. Four cribs were single chamber designs and four were tiered, resulting in 10 planting chambers. The remaining cribs will be constructed in spring 2025 and planted in fall 2025. Three-tiered chamber cribs were designed to meet three target elevations per crib (approximately 3.0 m, 2.7 m, and 2.4 m NAVD88) and single chamber cribs were built to be within the treatment range. We are planting nurse cribs with two bare root saplings of Sitka spruce and crab apple, and one twinberry per chamber in spring of 2025 and fall 2026. We will spray saplings with PlantSkydd repellant following budburst each spring to reduce likelihood of damage due to herbivory.

Soon after planting, and at least 1-2 times in the first few years of the experiment, we will measure soil volume and elevation at the top and base of the nurse cribs using RTK-GNSS to document potential settling of the cribs and sediment accumulation or scour at the base of cribs. At the beginning of the growing season in spring 2025 we will assess plant survivorship; if any saplings do not survive initial planting we will replace them since their loss may be due to transplantation stress and not treatment effects. Annually starting in late summer 2025, we will assess survivorship and growth of each plant by recording its condition (dead, nearly dead, alive but stressed, healthy), height (from substrate to top of shrub without extension), number of basal branches, and stem/trunk diameter at 25 cm above substrate surface for saplings <1.4 m in height and diameter at breast height (DBH) for trees >1.4 m in height. Where DBH cannot be reached, especially in taller cribs, stem diameter will be measured 25 cm above substrate and noted in the datasheet. We will also measure herbaceous cover annually with ocular estimates on the cribs. To quantify substrate water content during the summer dry season, we will measure soil moisture semi-monthly with a TEROS 12 soil moisture and electrical conductivity probe at three points in each chamber approximately 10 cm below the crib soil surface. We will conduct these measurements at a 0.6 m or lower tide and within the monthly neap tide period during the dry season (May-October) for at least the first two years of growth. Measurements will include volumetric percent water content, soil temperature, and saturation extract electrical conductivity (mS cm^{-1}).

In addition to the nurse crib elevation experiment, we will plant tidal forested swamp species in mounds created during the earthmoving phase of implementation and in areas of higher elevation that were not scraped for RCG removal during implementation. These areas may vary in elevation, but were not designed to capture specific elevations. Planting will occur from late 2025 to early 2026.

Figure 16. Examples of single chamber nurse crib (at left) and three-tiered nurse crib (at right) built in WZ1.

4.14.4 Upland forest vegetation and woody debris

To examine the effects of variable density thinning on upland vegetation and woody debris in WZ5, we will use methods based on the Forest Inventory Analysis (FIA) developed by the USFS and other protocols (Elzinga et al. 1998, Takenaka et al. 1998). The "FIA Light" design for WZ5 monitoring consists of a single subplot, compared to four subplots which make up a standard FIA plot (Westfall et al. 2022). Sampling includes measurements of tree health (compacted crown ratio, where < 30% indicates poor health), growth rate (tree-ring data from trunk cores and diameter at breast height; DBH), density (trees per acre), forest structural complexity (tree height and canopy class), species diversity, and community structure (composition and abundance) (Table 9, Figure 17). The FIA protocol also includes measurement of understory vegetation (percent cover of forbs, graminoids, seedlings, and moss) and woody debris (count, size, and decay class). Trees, understory vegetation and woody debris are measured in plots of different sizes (Table 9). Additional understory measurements include stem architecture (Takenaka et al. 1998) and community composition and cover in addition to FIA methods (Elzinga et al. 1998). Understory monitoring will be conducted in early summer to capture maximum flowering and fruiting period (Wender et al. 2004).

We determined subplot locations using a stratified random design, where strata included stand age (young = approximately 20 years old, mid = approximately 30 years old, and old ≥ 50 years) and forest prescription (thinned, skips, gaps, control outside project area). We generated random locations within each stratum using the Create Random Points tool in ArcGIS Pro software. FIA Light plots are replicated three times per combination of stand age and prescription treatment resulting in nine plots in thinned areas, nine plots in skips, nine plots in gaps, and five plots outside the management unit (reference plots) for a total of 32 plots. Of the 32 plots, we designated 12 plots to supplement baseline vegetation monitoring with additional measurements (referred to as "forest focus plots"), including bird and salamander surveys (sections 4.15, 4.21) and forest microclimate monitoring (section 4.11). All 32 plots will also include wildlife cameras for monitoring wildlife use and populations (section 4.19).

Figure 17. Illustration of several components of the forest inventory analysis of forest plots. From left to right: measuring tree diameter at breast height, measuring tree height with laser rangefinder, quantifying canopy cover, and counting fine woody debris.

Table 9. FIA Light plot design and layout of monitoring units. Each monitoring unit measures different components of forest vegetation and has a unique radius or transect length.

Monitoring Unit	Unit size and arrangement	Biota or factor measured	Parameters measured
Macroplot	Circular plot with 19.95 m radius.	Large trees (>76.2 cm DBH), average size tree (tree core).	DBH, height; live/dead, compacted crown ratio, distance from center, compass bearing from center, canopy class, age (tree rings).
Subplot	Circular plot with 7.32 m radius.	Trees (>12.7 cm DBH), saplings (2.5 cm to 12.6 cm DBH), shrubs, understory.	Same as the macroplot, as well as: photo (each cardinal direction), canopy cover (each cardinal direction), stem architecture and morphology.
Microplot	Circular plot with 2.07 m radius, with center located at 3.66 m at 90° from subplot center.	Understory forbs, graminoids, shrubs, seedlings, moss.	% cover per species.
Coarse woody debris transect	Transect from subplot center to subplot edge (14.6 m long), oriented at 90° and 270°.	Coarse wood (>7.6 cm diameter).	Distance from center, compass bearing from center (90 or 270), diameter, length, decay class.
Fine woody debris transect	Segment of 270° transect, from 4.3 m to 6.1 m from plot center for small and medium size classes, and from 4.3 m to 7.32 m for large size class.	Fine wood size classes (diameter): small (<0.61 cm), medium (0.62 cm to 2.29 cm), large (2.3 cm to 7.37 cm)	Count per size class.
Canopy cover	Center of plot facing four cardinal directions.	Tree canopy	Canopy cover using densiometer.
Litter	Within 1 m of each end of woody debris transect .	Litter and duff	Depth of the litter and duff layers.
Weather station	Center of subplot in focus plots only, data collected on loggers every 15 min from June-November.	Weather conditions	Temperature and humidity.

4.15. Bird abundance and composition

4.15.1 Wetland and forest birds

Birds are a higher trophic level indicator of ecosystem health in coastal and estuarine ecosystems. The presence and abundance of each species are indicative of their particular habitats and the abundance of food sources. Tracking threatened species in particular, like marbled murrelet (*Brachyramphus marmoratus*), which rely on both old-growth forests for nesting and nearshore waters for foraging, is essential for evaluating the successful restoration and function of forests in estuarine watersheds.

Pre-restoration bird surveys were conducted in 2015-2016 and 2021-2023 to generate baseline data for the Wasson restoration. These lowland surveys consisted of a 2.1 km-long line transect positioned along the center of Wasson Valley stretching from WZ1 to WZ4 (Beeken 2016). Bird data included time of detection, species, distance from transect line to bird, habitat association (marsh, forest, marsh/forest interface) and detection type (e.g., visual, call, song, flyover). The area of observation extended into the forest for audible calls, approximately 100 m to either side of the transect line. The surveys were conducted twice monthly from December 2015 through February 2016 and then weekly through May 2016. Following restoration implementation, we will repeat these surveys annually during the early post-restoration period for three years and then every three years for long-term monitoring. We will use the transect data to assess bird community change in Wasson over time.

In 2021 we tested a revised method for assessing change over time and for comparing the Wasson Valley with two reference areas (AND and TOC). We found that the transect method was not possible in reference sites due to obstructions (extensive shrubs, wetlands, and beaver dams) that prevented observers from walking up the center of the valleys, therefore we tested the use of point count stations (Huff et al. 2000). We selected three point-count stations (for five minute observation periods) in Wasson Valley and two point-count stations in the nearby Anderson Valley for sampling three times from 5 May 2021 through 10 June 2021. Bird data included time of detection, species observed, distance from transect line to bird, habitat association (marsh, forest, marsh/forest interface) and detection type. Distance of observation extended into the forest for audible calls, approximately 100 m radius around the point count station. We then expanded the surveys in 2023 to include an additional point-count station in Wasson Valley, two point-count stations in TOC, and two stations in WIN-TS for a total of 10 bird survey point-count stations. We sampled these four times between 1 May and 16 June 2023 as well as in 2024. During the early post-restoration period, we will sample these stations annually (every two weeks from May through June) and every three years thereafter for long term monitoring. We will use the point count data to determine bird community change over time relative to bird community change in reference sites. We will also use this point count method to assess changes in bird use related to restoration treatment at 12 upland forest focus sites (section 4.14.4).

4.15.2 Marbled murrelet

Certified observers surveyed forested areas near Wasson Valley for marbled murrelet activity for two consecutive years prior to restoration. The project area was split into five sites, with five stations per site, as per established protocols (Mack et al. 2003). Survey methods follow established protocols, which are detailed in Mack et al. (2003) and must be conducted by certified observers. Surveys are conducted during the breeding season (May 1 - August 5), with initial surveys within the first two weeks of the breeding season (May 1 - May 14) followed by two surveys per site during the peak activity period (June 30 - July 18). Stations are visited multiple times (minimum of five visits; nine visits when birds are detected) over evenly spaced intervals (sampling intervals between 6-30 days) during the breeding season. Surveys are conducted over a two-hour period beginning 45 minutes before sunrise and ending 75 minutes after sunrise. The data collected by the field observer includes murrelet detections, other bird species observed during the survey period, and environmental conditions at the time of the survey, including precipitation, wind speed, cloud height, and fog density (Mack et al. 2003). No recommendations are available for a post-restoration monitoring timeline; however, based on tree limb development it is likely to take decades to develop suitable habitat in much of the restoration area. Post-restoration monitoring is recommended at 10 year intervals.

4.16. Beaver activity

Beavers are important wetland engineers, adding complexity to wetland habitats that support many species of fish and wildlife. Their dams and ponds slow down and filter sediments and pollutants and store water, helping improve water quality and preventing downstream flooding (Kemp et al. 2012, Pollok et al. 2014, Pollock et al. 2023). To understand changes to the distribution and density of beaver in Wasson Valley, we will conduct annual spring beaver surveys in WZ1-4 and at three reference sites (TOC, AND, and WIN-TS). Using protocols adapted from the Wetlands Conservancy (TWC and JCWC 2022) we will record dam density, size, and condition; bank dens; and other signs of beaver activity such as the number and location of trench canals, slides, and prints. At each study site the entire area will be observed (Figure 2). At each dam, we will note dam condition, the composition of building materials, dam length, water level difference, whether it's an active dam, and if water is overflowing the top of the dam (Figure 18). Field teams will consist of two people using a FieldMaps form and a handheld GPS device.

Figure 18. A field researcher measuring beaver dam length and height (left), large beaver dam at Tom's Creek Marsh (middle), and human-made beaver dam analogs (right).

4.17. Fish presence and abundance

4.17.1 Lamprey

The Coos Estuary provides spawning and rearing habitat for two native lamprey species - Western brook lamprey (*Lampetra richardsoni*) and the Pacific lamprey (*Entosphenus tridentatus*) - both of which are listed as sensitive species in the state of Oregon (ODFW 2021). Pacific lamprey are anadromous fish that are hatched and reared in coastal streams of western North America, migrate to the ocean as adults, and then return to stream environments to spawn (Clemens et al. 2019). Records at dams in several major Oregon rivers suggest that Pacific lamprey have experienced long-term population decline, although more recent nest count data on the Oregon coast suggest current population stability (Clemens et al. 2021). Western brook lamprey are life-long residents of coastal Oregon streams, living up to nine years (Kostow 2002). Lamprey are a culturally-important species to Tribal Nations in the PNW (Clemens et al. 2019).

To assess lamprey use of stream habitat in Wasson Valley and nearby Winchester Creek, we will quantify lamprey population abundance using electroshocking techniques (Litts et al. 2023) at replicate channel reaches in the two stream systems. Stream reaches are approximately 50 m long and located in areas considered optimal habitat for lamprey ammocoetes, which are the larval filter-feeding life stage that burrows into soft stream sediments (optimal habitat is slow moving water with at least 15 cm of unconsolidated fine sediments). We will document reaches with GPS and photographs, and physically mark locations with flagging in the field. At the time of sampling, a field team of four will visit each channel reach. Two netters and one person operating an ABP-2 backpack electroshocker will walk the entire reach, while a streamside data recorder will document ammocoetes caught with nets and those seen but not netted (Figure 19). Fish that are caught are temporarily held in buckets. The team will repeat the walk through the entire reach during a second pass to catch any additional fish. For each lamprey caught, fish length and life stage will be recorded. If a lamprey is greater than 70 mm long it will be identified to species. For each 50 m channel reach, the team will also record habitat characteristics including water temperature, length of reach features such as pools and riffles, channel width, maximum and average water depth, and sediment characteristics.

As a second method to track lamprey use of the Winchester stream network we will also use environmental DNA (eDNA). In Wasson Valley, we will sample annually (during summer) at sites located in WZ1-4. We will collect and analyze samples using USFS protocols (Carim 2016). Briefly, 5 L of stream water is pumped through a glass fiber filter (WF 934-AH) using a peristaltic pump. The filter is removed and placed in a plastic bag with desiccant. Filters are then sent to the USFS genomics lab for analysis using quantitative polymerase chain reaction methods.

Figure 19. Researchers using a lamprey-specific electroshocker and nets to collect ammocoetes from a section of stream (left). Captured lamprey are sedated, measured, and identified to species and life cycle stage (right) before being released back into the stream.

4.17.2 Coho

Coho salmon (*Oncorhynchus kisutch*) are another anadromous species endemic to the Pacific coast of North America. They are one of several salmonid species that utilize estuarine habitats during part of their life cycle (Jones et al. 2021). Coho in the South Slough watershed are at risk, with data from ODFW's LCM program indicating that the Winchester Creek coho run is in critical condition because suitable spawning habitat is limited (P. Burns, personal communication). The only known spawning reach for the entire watershed is a 1.2 km section of the West Fork Winchester Creek. However, since upper Wasson Creek has suitable grade and substrate for coho to spawn, there is a possibility that adults may move into Wasson for spawning purposes following improved conditions in Lower Wasson Creek after restoration.

Spawning surveys were conducted in Wasson prior to restoration (2015-2017) using ODFW LCM protocols by walking an approximately 1 km channel reach for spawning (downstream to upstream) every 10 days (or less) during spawning season (following the first major rain event in November or early December, to late January). The downstream start of the reach was the upper end of WZ4 and the upstream end was a natural barrier (1.5 m tall waterfall). Within the reach, the team collected data on the number of redds (nests) observed, and the number of live and dead adults and jacks. When a dead salmon was observed, the team collected data on species, sex, length (mid eye to last posterior scale), and any markings (tags or removed adipose fin). Tails were removed from dead fish that were measured, and carcasses left on site. When live fish were observed during a survey, the team noted fish behavior and spawning status. At the end of the survey, the team collected data for the channel reach including weather conditions, general stream flow, and visibility. Following restoration actions in Wasson Valley, we will conduct spawning surveys in the same reach.

To better understand adult and juvenile coho use of Wasson Valley stream habitat, we will also collect eDNA samples from water obtained during low-flow summer conditions in WZ1-4. We will sample eDNA at three sites at the end of the spawning season (January) including the spawning area above WZ4 (43.2754°N, 124.3395°W), a location just above the pinch point in lower WZ4 (43.2741°N, 124.3335°W), and a site in WZ2 just above the tidal influence (43.2711°N, 124.3225°W). To sample eDNA, we will filter 5 L of stream water through a glass microfiber filter using a peristaltic pump, preserve samples by desiccation, and analyze them for species presence using quantitative polymerase chain reaction methods (Figure 20).

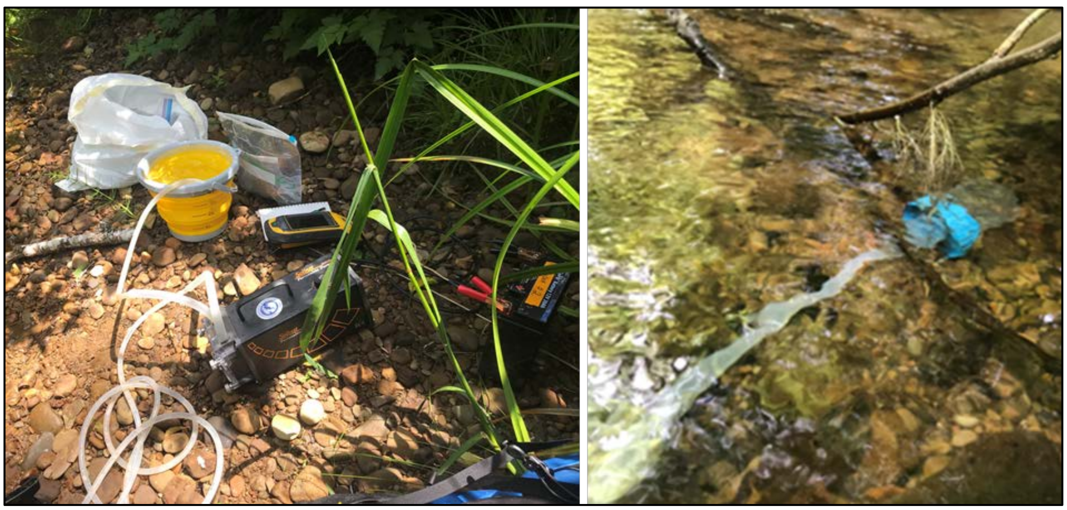

Figure 18. eDNA sampling kit setup (left) to collect filtered water samples from a stream (right).

4.17.3 Eulachon

Eulachon (*Thaleichthys pacificus*) are an anadromous smelt species. The National Marine Fisheries Service listed the southern distinct population segment of this species (occurring from British Columbia to Northern California) as threatened under the Endangered Species Act (NOAA 2024). In Oregon the spawning migration to rivers usually occurs in late winter (James et al. 2014). Larvae will use estuaries before migration out to the open ocean (NOAA 2024). Therefore, the peak signal for eDNA is expected in late March and early April.

To detect eulachon presence, we will collect water samples for eDNA analysis annually in April correlating with the end of eulachon spawning season. We will sample annually for 10 years post restoration. Sampling sites will include lower Wasson Creek and nearby reference sites including AND, TOM, and Winchester Creek (at the Hinch Bridge). As in section 4.17.2, we will collect eDNA samples by filtering 5L of stream water and analyzing them with quantitative polymerase chain reaction methods.

4.18. Stream macroinvertebrates

4.18.1 Aquatic macroinvertebrate assemblages

Macroinvertebrate assemblages can be indicators of stream conditions prior to and following restoration actions. Macroinvertebrate biomass for example indicates potential food available for insectivorous fish in stream and tidal channel habitats and macroinvertebrate species composition can be a strong indicator of healthy stream habitat (McDonald et al. 1991, US EPA 2013).

To assess changes in benthic macroinvertebrate abundance, composition, and diversity we will collect data at five randomly selected pool locations in WZ2, AND, and TOC following elements from Braccia et al. (2023), Jennings et al. (2023), and DEQ (2009). Pre- and post-restoration sampling will occur during the spring (late April to mid-May). At each pool, observers will use a D-frame net with 500 µm mesh to collect surface animals and sediment (to 1 cm depth) working in a downstream to upstream direction (Figure 21). The team will work at an approximate rate of 1 meter for every 6 seconds for a total of 60 seconds and will measure the total area sampled. After a sample is obtained, streamside processing will include removal of large debris (anything >4 cm diameter) after checking for attached invertebrates first.

The field team will empty the contents of the net into a 500 µm mesh-bottomed sieve bucket that is then dipped repeatedly into the stream to rinse out fine sediment particles. Sample processing will include agitation to suspend and remove organic material; collection of larger invertebrates such as snails, clams, and caddisfly larvae; and return of remaining mineral sediments to the stream. Recovered invertebrates will be preserved in 95% ethanol and sent to Aquatic Biology Associates for identification.

Figure 19. A researcher collecting benthic samples using a D-net, for macroinvertebrate identification.

4.18.2 Freshwater mussel assessment

Several species of native freshwater mussels inhabit rivers and streams in western Oregon, including the western ridged mussel (*Gonidea angulata*), western pearlshell (*Margaritifera falcata*), and several species of floater mussels (*Anodonta* spp.). Using BLM protocols, a mussel expert conducted a preliminary survey at WZ2 and TOC during summer low flow conditions to assess whether mussels occur in the project area (BLM 2023). Observations along diagonal bank-to-bank transects against primary flow, focusing on preferred habitat of unconsolidated substrates and along undercut banks, suggested that no mussels were present. If mussels are detected in Wasson Valley during the course of monitoring for other parameters, we will start monitoring using BLM protocols by conducting snorkel surveys in WZ2-4 and at TOC.

4.19. Wildlife populations

4.19.1 General wildlife use

Many wildlife species are difficult to research due to their highly mobile and often secretive habits. To characterize general wildlife use of Wasson habitats, we will conduct a species inventory in Wasson Valley (WZ1-3) and in upland forest (WZ5) using wildlife cameras to compare patterns of wildlife abundance and composition and temporal variability in wildlife habitat use before and after restoration actions. Between 2022 and 2024 we placed five cameras in WZ1-3, 32 cameras in WZ5, and two cameras in TOC (Raposa et al. 2025) (Figure 22). Cameras are located away from roads and developed areas and in areas where wildlife traffic or other signs of wildlife use (e.g., active beaver dam) have been noted and the field of view has <30% cover by water. Cameras are spaced a minimum of 100 m apart. Cameras are mounted approximately 1 m above the ground surface and angled down slightly (~3-5 degrees). In areas prone to false triggers due to vegetation moving in the wind, plants can be trimmed slightly (but not so much as to change site characteristics). Cameras have passive infrared sensors that are programmed to trigger on movements that occur >5 minutes apart to avoid counting the same animal multiple times.

Figure 20. Wildlife camera mounted at newly graded Wasson Valley (left); and mounted camera in the beaver-dominated marsh of Tom's Creek (right).

4.19.2 Black-tailed deer use and population

Since variable density thinning of forest trees aims to increase habitat diversity and understory plant abundance and diversity, it is assumed to benefit large herbivores such as elk and deer. However, the response of these animals to forest restoration thinning is not well documented. Additionally, there are no known population estimates for black-tailed deer in the South Slough watershed. We will use wildlife camera detection and genetic analysis of deer scat to observe population size, frequency of habitat use, and spatial distribution of black-tailed deer in Wasson Valley and forested habitats (Ikeda et al. 2013). For camera monitoring, we will use the network of cameras installed in 32 forest plots (section 4.14.4). Camera height, angle, and azimuth (recorded at the time of camera setup) will vary at each location, depending on the proximity to active game trails in the surrounding forest plots. Each camera is positioned at a slight angle to these trails to monitor their length, maximizing the chances of detecting passing animals. From camera detection data, we will derive metrics such as changes in the frequency of detection per camera (that can indicate changing habitat preference), and changes in the number of detections within set time periods (which can indicate changes in relative population size).

For genetic analysis, dog detection teams will search nine cells for black-tailed deer scat, (500 m by 500 m in size), within both restored areas (WZ1-5) and reference forest immediately north/northeast of the restoration area. Pre-restoration samples were taken from 11 to 17 Jan 2024 and we will collect post-restoration samples following completion of all restoration actions (pending funding). Samples will be preserved in 95% ethanol avoiding as much soil and vegetation as possible. Vial labels will include date, time, sample number, and two-digit year to identify batch number and owner. Additional records include sample collection location, condition of sample, the dog's walking track, and the day's weather conditions. Samples will be shipped to the OSU genetics lab for analysis.

4.20. Mosquito abundance

Mosquitoes are an important component of wetland ecosystems, playing key roles in nutrient cycling and pollination, and supporting fish and wildlife as important prey items (Mazzacano and Black 2013). In some instances, they can also be a nuisance species when they occur in high abundance in estuaries (Bridgeland et al. 2017). In a given year, mosquito abundance may be related to a number of factors including rainfall, temperature, and persistence of water bodies suitable for egg laying and rearing (Claire 2019).

We will monitor adult mosquito populations using traps to document their abundance in Wasson Valley restoration zones and in reference areas (Tom's Creek near Hinch Bridge, Hidden Creek marsh). We will trap adult mosquitoes using a Carbon Dioxide baited Encephalitis Virus Surveillance (EVS/CO_2) trap, which uses both dry ice and light as attractants. We will set traps at dusk and remove them the following morning to sort samples. We will set out traps twice per month during the dry season (July-October) during neap tide periods (targeting nights without predicted rainfall or high winds). Samples will be stored frozen, thawed at the time of analysis, and counted by spreading them out on a sheet of white paper. After counting we will preserve samples by drying them (50-75°C) in glass vials and storing them in a freezer until they can be shipped for identification (preservation methods from Janousek et al. 2021a, chapter 8). We will calculate catch per unit effort per site.

4.21. Salamander abundance

Salamanders are sensitive to forest microhabitat conditions, particularly humidity and vegetation cover. As predators they are also expected to respond to invertebrate prey availability (Hesed 2012) and therefore be good bioindicators of forest condition change with gap creation and thinning treatments. In addition, salamanders are charismatic fauna and are of interest to the public. We will assess salamander abundance using coverboards in the 12 forest focus plots described in section 4.14.4.

In each forest focus plot, we will place five coverboards (untreated pine boards, 40 cm by 25 cm by 5 cm), with one coverboard at the plot center and four positioned 5 m away in each cardinal direction (Hesed 2012; Figure 23). We will survey plots monthly starting in November 2024 prior to forest thinning activities, and continue surveys monthly for five years following treatments. Long-term post-restoration may continue every six months thereafter depending on early results.

Figure 23. Example coverboard setup for salamander surveys. Photo shows four of the five coverboards planned per monitoring plot.

5. Data management and analyses

5.1 General data management

We will conduct ecosystem monitoring using best data management practices throughout the project. Monitoring data collection in digital and written forms will follow standardized methods as outlined in this document. If adjustments to sampling protocols outlined in this monitoring plan are needed, we will document changes. In the field, we will periodically inspect written field sheets to ensure accuracy and completeness of data collection. After data collection, we will digitize any hand-written data records and inspect digital transcriptions for accuracy. We will periodically back up digitized data on physical hard drives and in cloud storage (e.g., a project folder available to all active team members). We will archive physical data sheets for a minimum period of 10 years at SSNERR.

To help ensure long-term continuity of monitoring, we will maintain a general inventory of monitoring datasets available to current and future monitoring team members. The inventory will include information on the type of data, its status (final or provisional), team members involved in data collection, its digital or physical location, and other relevant metadata. We will update the inventory annually.

5.2 Data QA/QC procedures

We will conduct QA/QC on all monitoring datasets before they are finalized and disseminated outside of the project team. General QA/QC steps relevant to most datasets described in this plan include inspection of data for outliers or transcription errors, basic graphical analyses, and production of summary statistics.

We will conduct additional QA/QC steps for specific monitoring parameters, including instrumentation (Table 10). For example, we will conduct periodic checks of instrument performance (e.g., checks of RTK-GNSS precision and accuracy on stable benchmarks and accuracy checks of analytical balances). We will periodically check the accuracy of data loggers used in tidal channels, stream habitat, and in groundwater wells to ensure reliability over the course of monitoring. We will recalibrate instruments as needed when instrument drift exceeds tolerances.

Table 10. List of specific QA/QC steps for use of data loggers and field and laboratory instrumentation in monitoring under this plan.

Instrument or logger type	QA/QC steps	Frequency
RTK-GNSS (section 4.01)	Accuracy and precision checks on permanent benchmarks.	Typically at beginning and end of each field campaign
Sprinter laser level (4.01)	Level collimation adjustment. Survey accuracy calculated via level loop misclosure.	Collimation adjustment and error check at beginning of every survey.
Water level loggers (4.02)	Accuracy checks of pressure at known water depths.	Once every 1-2 years.
Aquatroll 200 conductivity loggers (4.03)	Single-point calibration using calibration standard; refractometer readings prior to recalibration.	At first deployment then every two months.
Odyssey conductivity loggers (4.03)	Accuracy checks of salinity in a series of controlled water baths of varying salinity.	Once every 1-2 years.
Refractometer (4.03)	Checks and recalibration (as needed) with freshwater.	Prior to each field outing.
YSI hand-held temperature, salinity, and pH meters (4.03)	Accuracy checks with conductivity and pH standards; recalibration as needed.	Prior to each field campaign.
YSI sonde sensors (4.03)	Calibrations using YSI standard protocols: single-point conductivity (10 mS), single-point DO (100% saturation), two-point turbidity (0, 124 FNU). Post-deployment calibration checks in same standards.	Calibration prior to each deployment. Post-deployment check after each deployment prior to sensor cleaning.
Hobo MX2201 and Extech RHT30 temperature loggers (4.03, 4.07.1, 4.11)	For Hobo MX2201 loggers, factory calibration is used, with an accuracy of ± 0.5°C and <0.1°C drift/year. For Extech loggers, accuracy checks are done with a hand-held thermometer.	Extech checks at the time of installation in the field.
Analytical mass balance (4.08)	Accuracy checks with known masses. Profession instrument calibration.	Checks at each batch of samples weighed. Instrument calibration annually.
GHG analyzer (4.10)	Zero calibration, filter and desiccant replacement; software updates; diagnostics.	Monthly diagnostics. Service as needed depending on frequency of use and diagnostic results.
UAV sensors (4.06, 4.12.2,4.14.2)	Multispectral calibration panel screen capture. All missions with ground control points measured with RTK GPS (RSME in post-processing should be < 0.2). Photographs at start and end of flight to confirm cloud cover. LIDAR missions self-calibrate during flight.	Ground control points placed prior to each flight. RTK GPS, calibration photos are taken before and after flight.
TEROS 12 soil moisture, temperature and electrical conductivity sensor (4.14.3)	Used factory calibration for non-soil substrates, which has an accuracy of ± 5%.	NA

5.3 Data archiving and publication

After datasets have undergone relevant QA/QC procedures, we will finalize them for analyses, reporting, and dissemination to end-users. We will annotate final datasets with metadata, and generally share them in commonly-used formats such as .csv or .pdf files. We will publish datasets associated with the project in publicly available data repositories such as the Knowledge Network for Biocomplexity or Figshare (environmental, vegetation, and faunal data), the Smithsonian Environmental Research Center's Coastal Carbon Atlas (soil carbon and greenhouse gas emission data), and CDMO or Oregon Explorer (geospatial data). We will share monitoring results and discussion of ecological outcomes in reports and manuscripts.

5.4 Statistical analyses

We will use a variety of graphical, univariate, and multivariate statistical methods to analyze data collected under this monitoring plan to test the hypotheses outlined in Tables 3-5. Potential statistical tests include graphical methods for time series, linear and generalized linear models for univariate metrics, and ordination or multivariate models for multivariate datasets such as species composition (Tables 11-13). Additionally, we will explore the use of data synthesis assessments which combine multiple parameters into summaries of habitat condition. For example, assessments of stream attributes and riparian habitat can be conducted with the Stream Evolution Model scoring system (Cluer and Thorne 2014).

Table 11. Potential statistical tests to evaluate status and change in ***abiotic*** *monitoring parameters outlined in this monitoring plan.*

Parameter	**Example metric(s)**	**Potential statistical tests**
Elevation (4.01)	Mean (±SE) wetland surface elevation; rate of elevation change over time.	Linear models to compare sites and restoration periods.
Surface water and groundwater levels (4.02)	Daily and monthly min, mean (±SE), max water levels.	Summary statistics; linear models to compare sites, seasons, and restoration periods.
Tidal channel, groundwater, and stream water quality (4.03)	Mean nitrogen concentration, maximum turbidity, salinity, 7-day moving average (temperature)	Summary statistics; linear models to compare sites, seasons, and restoration periods.
Tidal channel and stream morphology (4.04)	Comparison of thalweg depths and widths at fixed locations	Graphical representation of change over time (Brophy et al. 2014).
Stream flow rates (4.05)	Mean and max flow rates	Linear models to compare sites, seasons, and restoration periods.
Habitat features (4.06)	Large wood log and jam complex movement over time; valley grade change over time; active channel width change over time	Linear models to compare sites; graphical representation of change over time.
Soil temperature (4.07)	Mean (±SE), min, max temps	Linear models to compare sites, seasons, and restoration periods.
Soil characteristics (4.08)	Mean (±SE) soil bulk density, organic matter content	Linear models to compare sites and restoration periods.
Sediment accretion (4.09)	Mean (±SE) vertical accretion rate per year	Linear models to compare sites and restoration periods.
GHG emissions (4.10)	Mean (±SE) CO_2 and CH_4 flux rates	Linear models to compare sites, seasons and restoration periods; multivariate models to estimate annual fluxes
Upland microclimates (4.20)	Temperature and relative humidity	Linear models (repeated measures ANOVA)
Biochar experiments (4.21)	Mean nutrient concentration	Linear models include treatment and time in interaction term

Table 12. Potential statistical tests to evaluate status and change in ***vegetation*** *monitoring parameters outlined in this monitoring plan.*

Parameter	Example metric(s)	Potential statistical tests
Emergent vegetation (4.11)	Mean (±SE) total plant cover and cover by species, species richness; species composition; total non-native plant cover	Linear models to compare sites and restoration periods; Nonmetric multidimensional scaling (NMDS); PERMANOVA, and species accumulation curves for composition and diversity
Woody vegetation plantings in Wasson Valley (4.14.1-2)	Percent cover by species, tree density, tree diameter	Linear models to compare sites, restoration periods, planting density and species mix
Woody vegetation in nurse crib experiment (4.14.3)	Tree survivorship, diameter	Linear models to assess elevation and substrate moisture effects
Woody vegetation in upland forests (4.14.4)	Percent cover by species, tree density, tree diameter, tree height, compacted crown ratio, canopy cover	Linear mixed effects models and model AICc model assessment (Fox and Weisberg 2023); NMDS and ANOSIM

Table 13. Potential statistical tests to evaluate status and change in ***wildlife*** *monitoring parameters outlined in this monitoring plan.*

Parameter	Example metric(s)	Potential statistical tests
Bird communities (4.15)	Species diversity; species composition	NMDS and VENN diagrams (Lewis and Starzomski 2015)
Beaver activity (4.16)	Beaver activity data	TWC and JCWC 2022
Fish presence and abundance (4.17)	Catch per unit effort (CPUE) abundance; Counts and species diversity at different life stages and tributaries	Linear models; Chi squared test or Jaccard similarity test for presence/absence eDNA data.
Stream macroinvertebrates (4.18)	Species relative abundance	Linear models; non-metric MDS
Wildlife populations (4.19)	Frequency of detection (per week); relative population estimates based on P/A during peak 30 min period	Linear models to compare sites and restoration periods
Mosquito abundance (4.20)	Mosquito abundance, change over time compared with reference sites	Qualitative change over time comparing reference and restoration sites
Salamander abundance (4.21)	Count and diversity from 3 replicates of 4 treatments	Repeated measures ANOVA (Hesed 2012)

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7. Citations

Beeken, M. 2016. Wasson avian inventory protocol. Aplodontia Services, Port Orford, OR. Report prepared for the South Slough National Estuarine Research Reserve. 10 pp.

Blount, K.J. 2017. Land use effects on carbon cycling in Oregon coastal wetlands. MS thesis, University of Oregon. Link.

Braccia, A., Lau, J., Robinson, J., Croasdaile, M., Park, J., Parola, A. 2023. Macroinvertebrate assemblages from a stream-wetland complex: a case study with implications for assessing restored hydrologic functions. Environmental Monitoring and Assessment 195:394. Link

Brand, M.W., Diefenderfer, H.L., Cornu, C.E., McKeon, M.A., Janousek, C.N., Borde, A.B., Souza, T.D., Keogh, M.E., Brown, C.A., Bridgham, S.D. 2025. Can restoring tidal wetlands reduce estuarine nuisance flooding of coasts under future sea-level rise? Earth's Future 13:e2023EF004149. Link

Bridgeland, W.T., Brophy, L., van de Wetering, S., So, K.J., van Hoy, R., Lowe, R.W., Ledig, D.B. 2017. Ni-les'tun tidal wetlands restoration project: Planning, implementation, and lessons learned. Washington, D.C.: U.S. Department of the Interior, Fish and Wildlife Service. Biological Technical Publication FWS/BTP-R1015-2017.

Brodie, L.C., Harrington, C.A. 2020. Guide to variable density thinning using skips and gaps. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. US Forest Service General Technical Report PNW-GTR-989, 46 pp. Link

Brodie, E.G., Knapp, E.E., Brooks, W.R., Drury, S.A., Ritchie, M.W. 2024. Forest thinning and prescribed burning treatments reduce wildfire severity and buffer the impacts of severe fire weather. Fire Ecology 20:17. Link

Brophy, L. 2005. Restoring freshwater wetlands in the South Slough National Estuarine Research Reserve: Links between water table elevation, soils, and plant communities in restored, altered, and undisturbed wetlands. Corvallis, OR: Green Point Consulting. Report prepared for South Slough National Estuarine Research Reserve, 42 pp.

Brophy, L.S., Cornu, C.E., Adamus, P.R., Christy, J.A., Gray, A., Huang, L., MacClellan, M.A., Doumbia, J.A., Tully, R.L. 2011. New tools for tidal wetland restoration: Development of a reference conditions database and a temperature sensor method for detecting tidal inundation in least-disturbed wetlands of Oregon, USA. Corvallis, OR: Report prepared for the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET). 199 pp. Link

Brophy, L.S., van de Wetering, S. 2012. Ni-les'tun tidal wetland restoration effectiveness monitoring: Baseline: 2010-2011. Corvallis, OR: Green Point Consulting, the Institute for Applied Ecology, and Confederated Tribes of Siletz Indians. Link

Brophy, L.S., van de Wetering, S., Ewald, M.J., Brown, L.A., Janousek, C.N. 2014. Ni-les'tun tidal wetland restoration effectiveness monitoring: Year 2 post-restoration (2013). Institute for Applied Ecology, Corvallis, OR. Link.

Brophy, L.S., Greene, C.M., Hare, V.C., Holycross, B., Lanier, A., Heady, W.N., O'Connor, K., Imaki, H., Haddad, T. and Dana, R. 2019. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. PLoS ONE 14:e0218558. Link

Brown, C., Mochon-Collura, T.C., Dewitt, T. 2024. Dataset: Accretion rates and carbon sequestration in Oregon salt marshes. Figshare data release. Link

Bureau of Land Management (BLM). 2023. Draft Visual Survey Protocol Framework for Western North American Freshwater Mussels, Version 1.3. Link

Cahoon, D.R., Turner, R.E. 1989. Accretion and canal impacts in a rapidly subsiding wetland II. Feldspar marker horizon technique. Estuaries 12:260-268. Link

Cahoon, D.R., Lynch, J.C., Pere, B.C., Segura, B., Holland, R.D., Stelly, C., Stephenson, G., Hensel, P. 2002. High-precision measurements of wetland sediment elevation: II. The rod surface elevation table. Journal of Sedimentary Research 72:734-739. Link

Cahoon, D.R., McKee, K.L., Morris, J.T. 2020. How plants influence resilience of salt marsh and mangrove wetlands to sea-level rise. Estuaries and Coasts 44:883-898. Link

Callaway, J.C. 2005. The challenge of restoring functioning salt marsh ecosystems. Journal of Coastal Research SI 40:24-36. Link

Carim, K.J., McKelvey, K.S., Young, M.K., Wilcox, T.M., Schwartz, M.K. 2016. A protocol for collecting environmental DNA samples from streams. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-355, 18 pp. Link

Claire, C. 2019. Coquille Valley Mosquito Monitoring Update. Prepared for Oregon Department of Fish and Wildlife. 6 pp.

Clemens, B.J., Weitkamp, L., Siwicke, K., Wade, J., Harris, J., Hess, J., Porter, L., Parker, K., Sutton, T., Orlov, A.M. 2019. Marine biology of the pacific lamprey *Entosphenus tridentatus*. Reviews in Fish Biology and Fisheries 29:767-788. Link

Clemens, B.J., Weeber, M.A., Lewis, M. 2021. Abundance trends for adult Pacific lamprey in western Oregon (USA): Historic declines, recent increases, and relative contributions from coastal rivers. Transactions of the American Fisheries Society 150:761-776. Link

Cluer, B., Thorne, C.R. 2013. A stream evolution model integrating habitat and ecosystem benefits. River Research and Applications 30:135-154. Link

Conroy, T., Sutherland, D.A., Ralston, D.K. 2020. Estuarine exchange flow variability in a seasonal, segmented estuary. Journal of Physical Oceanography 50:595-613. Link

Coquille Watershed Association, The Nature Conservancy in Oregon, and Tillamook Estuaries Partnership (CoqWA, TNC, TEP). 2024. Tide gate and tidal wetland monitoring: guidance and protocols for estuary practitioners. Coquille, Portland, and Garibaldi, OR. Prepared for the Oregon Watershed Enhancement Board. Link

Cornu, C.E., Sadro, S. 2002. Physical and functional responses to experimental marsh surface elevation manipulation in Coos Bay's South Slough. Restoration Ecology 10:474-486. Link

Department of Environmental Quality (DEQ). 2009. Water monitoring and assessment mode of operations manual, version 3.2. DEQ03-LAB-Lab0036-SOP. Hillsboro, OR: Oregon Department of Environmental Quality, Laboratory and Environmental Assessment Division. Link

Drexler, J.Z., Fuller, C.C., Archfield, S. 2018. The approaching obsolescence of ^{137}Cs dating of wetland soils in North America. Quaternary Science Reviews 199:83-96. Link

Eidam, E.F., Sutherland, D.A., Ralston, D.K., Dye, B., Conroy, T., Schmitt, J., Ruggiero, P. and Wood, J., 2020. Impacts of 150 years of shoreline and bathymetric change in the Coos Estuary, Oregon, USA. Estuaries and Coasts 45:1170–1188. Link

Eidam, E.F., Sutherland, D.A., Ralston, D.K., Conroy, T., Dye, B. 2021. Shifting sediment dynamics in the Coos Bay Estuary in response to 150 years of modification. JGR Oceans 126:e2020JC016771. Link

Elzinga, C.L., Salzer, D.W., Willoughby, J.W. 1998. Measuring and monitoring plant populations. Denver, CO: Bureau of Land Management Technical Reference 1730-01. Link

Fitch, A.A., Blount, K., Reynolds, L., Bridgham, S.D. 2022. Partial recovery of microbial function in restored coastal marshes of Oregon, USA. Soil Science Society of America Journal. 86:831-846. Link

Fox, J., Weisberg, S. 2023. Mixed-effects models in R. An appendix to an R companion to applied regression, 2nd ed., 54 pp. Link

Franklin, J. F., Dyress, C.T. 1973. Natural vegetation of Oregon and Washington. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-008, 427 pp. Link

Haider, G., Steffens D., Moser, G., Müller C., Kammann, C.I. 2017. Biochar reduced nitrate leaching and improved soil moisture content without yield improvements in a four-year field study. Agriculture, Ecosystems and Environment 237: 80-94. Link

Heiri, O., Lotter, A.F., Lemcke, G. 2001. Loss on ignition for estimating organic and carbonate content in sediments: Reproducibility and comparability of results. Journal of Paleolimnology 25:101-110. Link

Hesed, K.M. 2012. Uncovering salamander ecology: A review of coverboard design. Journal of Herpetology 4:442-450. Link

Hoffnagle, J.R. 1980. Estimates of vascular plant primary production in a west coast saltmarsh-estuary ecosystem. Northwest Science 54:68-79.

Hood, W.G. 2020. Applying tidal landform scaling to habitat restoration planning, design, and monitoring. Estuarine Coastal and Shelf Science 244:106060. Link

Huff, M.H., Bettinger, K.A., Ferguson, H.L., Brown, M.J., Altman, B. 2000. A habitat-based point-count protocol for terrestrial birds, emphasizing Washington and Oregon. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-501, 39 pp. Link

Ikeda, T., Takahashi, H., Yoshida, T., Igota, H., Kaji, K. 2013. Evaluation of camera trap surveys for estimation of sitka deer herd composition. Mammal Study 38:29-33. Link

James, B.W., O.P. Langness, P.E. Dionne, C.W. Wagemann and B.J. Cady. 2014. Columbia River eulachon spawning stock biomass estimation. Report A, In: C. Mallette (ed.), Studies of eulachon smelt in Oregon and Washington, prepared for the National Oceanic and Atmospheric Administration, Washington, DC, by the Oregon Department of Fish and Wildlife and the Washington Department of Fish and Wildlife. Grant No.: NA10NMF4720038. Link

Janousek, C.N., Thorne, K.M., Takekawa, J.Y. 2019. Vertical zonation and niche breadth of tidal marsh plants along the northeast Pacific coast. Estuaries and Coasts 42:85-98. Link

Janousek, C.N., Bailey, S., van de Wetering, S., Brophy, L., Bridgham, S., Schultz, M., Tice-Lewis, M. 2021a. Early post-restoration recovery of tidal wetland structure and function at the Southern Flow Corridor project, Tillamook Bay, Oregon. Corvallis, OR: Oregon State University, Tillamook Estuaries Partnership, Confederated Tribes of Siletz Indians, Institute for Applied Ecology, and University of Oregon. Link

Janousek, C.N., Bailey, S.J., Brophy, L.S. 2021b. Early ecosystem development varies with elevation and pre-restoration land use/land cover in a Pacific Northwest tidal wetland restoration project. Estuaries and Coasts 44:13-29. Link

Janousek, C.N., Williams, T. 2024. Tidal wetland monitoring plan for the central Oregon coast. Corvallis, OR: Prepared for MidCoast Watersheds Council by Oregon State University. Link

Janousek, C.N., Krause, J.R., Drexler, J.Z., Buffington, K.J., Poppe, K.L., Peck, E., Adame, M.F., Watson, E.B., Holmquist, J. et al. 2025. Blue carbon stocks along the Pacific coast of North America are mainly driven by local rather than regional factors. Global Biogeochemical Cycles 39:e2024GB008239. Link

Janousek C., Williams, T., McKeon, M., Bridgham, S.D., Cornu, C., Diefenderfer, H., Borde, A., Norwood, M., Apple, J., Brophy, L. 2025. Dataset: Fluxes of carbon dioxide, methane, and nitrous oxide and associated environmental data from estuarine wetlands in the Pacific Northwest, USA. Figshare data release. Link

Jennings, J.C., Bellmore, J.R., Armstrong, J.B., Wisseman, R.W. 2023. Effects of process-based floodplain restoration on aquatic macroinvertebrate production and community structure. River Research and Applications 39:1709-1723. Link

Johnson, G.M., Sutherland, D.A., Roering, J.J., Mathabane, N., Gavin, D.G. 2019. Estuarine dissolved oxygen history inferred from sedimentary trace metal and organic matter preservation. Estuaries and Coasts 42:1211-1225. Link

Jones, K.K., Cornwell, T.J., Bottom, D.L., Stein, S., Starcevich, S. 2021. Interannual variability in life-stage specific survival and life history diversity of coho salmon in a coastal Oregon basin. Canadian Journal of Fisheries and Aquatic Sciences 78:1887-1899. Link

Kauffman, J.B., Giovanonni, L., Kelly, J., Dunstan, N., Borde, A., Diefenderfer, H., Cornu, C., Janousek, C., Apple, J., Brophy, L. 2020. Total ecosystem carbon stocks at the marine-terrestrial interface: Blue carbon of the Pacific Northwest Coast, United States. Global Change Biology 26:5679-5692. Link

Keammerer, H.B., Hacker, S.D. 2013. Negative and neutral marsh plant interactions dominate in early life stages and across physical gradients in an Oregon estuary. Plant Ecology 214:303-315. Link

Keane, R.E. 2006. Tree data (TD) sampling methods. U.S. Department of Agriculture, Forest Service, General Technical Report RMRS-GTR-164-CD. Link

Kemp, P.S., Worthington, T.A., Langford, T.E.L., Tree, A.R.J., Gaywood, M.J. 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. Fish and Fisheries 13:158-181. Link

Kostow, K. 2002. Oregon lampreys: natural history, status, and problem analysis. Oregon Department of Fish and Wildlife [Fish Division]. Link

Lemke, J.L. 2006. Fish use of estuarine tidal channels enhanced with large woody debris. Forest Grove, OR: ABR Inc. Environmental Research and Services. Report prepared for the South Slough National Estuarine Research Reserve, 13 pp. Link

Lewis, K., Starzomski, B. 2015. Bird communities and vegetation associations across a treeline ecotone in the Mealy Mountains, Labrador, which is an understudied part of the boreal forest. Canadian Journal of Zoology 93:477-486. Link

Litts, R., Clemens, B.J., Vonderohe, G., Schaefer, J. 2023. Backpack electrofishing can be used to collect adult lamprey. North American Journal of Fisheries Management 43:1623-1630. Link

Mack, D.E., Ritchie, W.P., Nelson, S.K., Kuo-Harrison, E., Harrison, P., Hamer, T.E. 2003. Methods for surveying marbled murrelets in forests: a revised protocol for land management and research. Pacific Seabird Group Technical Publication Number 2. Link

Marin Jarrin, M.J., Sutherland, D.A., Helms, A.R. 2022. Water temperature variability in the Coos Estuary and its potential link to eelgrass loss. Frontiers in Marine Science 9:930440. Link

Mazzacano, C., Black, S.H. 2013. Ecologically Sounds Mosquito Management in Wetlands: An overview of mosquito control practices, the risks, benefits, and non-target impacts, and recommendations on effective practices that control mosquitoes, reduce pesticide use, and conserve wetlands. Portland, OR: The Xerces Society for Invertebrate Conservation, 63 pp. Link

McDonald, B.S., Mullins, G.W., Lewis, S. 1991. Macroinvertebrates as indicators of stream health. The American Biology Teacher 53:462-466. Link

Miller, B.A., Sadro, S. 2003. Residence time and seasonal movements of juvenile Coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132:546–559. Link

Moore, K., Jones, K., Dambacher, J., Stein, C. et al. 2023. Aquatic Inventories Program. Methods for Stream Habitat and Snorkel surveys. Corvallis, OR: Conservation and Recovery Program, Oregon Department of Fish and Wildlife. Link

National Oceanic and Atmospheric Administration (NOAA). 2012. Sentinel sites program guidance for climate change impacts. National Estuarine Research Reserve System. Link

National Oceanic and Atmospheric Administration (NOAA). 2016. Coastal Habitat Response to Changing Water Levels: NERR Sentinel Site Application Module 1, 20 pp. Link

National Oceanic and Atmospheric Administration (NOAA). 2024. Eulachon. NOAA Fisheries. Accessed 5 May 2025. Link

National Oceanic and Atmospheric Administration's National Estuarine Research Reserve System (NOAA NERRS). 2023. System-wide Monitoring Program Data Management Manual, v.6.6. Centralized Data Management Office, 221 pp. Link

Nelson, A.R., Jennings, A.E., Kashima, K. 1996. An earthquake history derived from stratigraphic and microfossil evidence of relative sea-level change at Coos Bay, southern coastal Oregon. Geological Society of America Bulletin 108:141-154. Link

Neubauer, S.C., Megonigal, J.P. 2015. Moving beyond global warming potentials to quantify the climatic role of ecosystems. Ecosystems 18:1000-13. Link

Oregon Department of Fish and Wildlife (ODFW). 2021. Oregon Department of Fish and Wildlife Sensitive Species List. Link

Peet, R.K., Wentworth, T.R., White, P.S. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63:262-274. Link

Pollock, M.M., Beechie, T.J., Wheaton, J.M., Jordan, C.E., Bouwes, N., Weber, N. 2014. Using beaver dams to restore incised stream ecosystems. BioScience 64:279-90. Link

Pollock, M.M., Lewallen, G., Woodruff, K., Jordan, C.E., Castro, J.M. 2023. The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains. Version 2.02. Portland, OR: United States Fish and Wildlife Service, 189 pp. Link

Poppe, K., Rybczyk, J.M. 2021. Tidal marsh restoration enhances sediment accretion and carbon accumulation in the Stillaguamish River estuary, Washington. PLoS ONE 16:e0257244. Link

Poppe, K., Bridgham, S.D., Janousek, C., Williams, T., Cornu, C., Perillat, H., Rybczyk, J., Diefenderfer, H., Borde, A., Tobias, F., Yonemura, R., Wright, A., Brophy, L.S., Giovannoni, L., Apple, J. 2024. Dataset: Soil carbon stocks and long-term accretion rates in tidal marshes, tidal swamps, and former tidal wetlands in eight estuaries in the Pacific Northwest, USA. Smithsonian Environmental Research Center data release. Link

Puckett, B., Falvo, C., Deaton, C., Morse, B., Smith, E., Ridge, J. 2022. A protocol for monitoring coastal wetlands with drones: Image acquisition, processing, and analysis workflows. National Estuarine Research Reserve System Science Collaborative. 73 pp. Link

Raposa, K., Cressman, K., vanProosdij, D., Goldstein, J., Stevens, R.A., Tyrell, M., DeGasperis, B., St. Laurent, K., Wasson, K., et al. 2025. The secret life of tidal marshes and mangroves: camera trapping as a window into wildlife using North American coastal wetlands. Manuscript in preparation.

Recht, F., Brophy, L.S., Drinkwin, J. 2024. Restoring tidal swamps in the U.S. Pacific Northwest: Information for restoration practitioners. Pacific States Marine Fisheries Commission, Pacific Marine & Estuarine Fish Habitat Partnership, and the Institute for Applied Ecology, 44 pp. Link

Roegner, G.C., Diefenderfer, H.L., Borde, A.B., Thom, R.M., Dawley, E.M., Whiting, A.H., Zimmerman, S.A., Johnson GE. 2009. Protocols for monitoring habitat restoration projects in the lower Columbia River and estuary. Seattle, WA: U.S. Department of Commerce, NOAA Technical Memo, NMFS-NWFSC-97, 63 pp. Link

Roman, C.T., Janes-Piri, M.J., Heltshe, J.F. 2001. Monitoring salt marsh vegetation. Wellfeet, MA: U.S. Geological Survey, Patuxent Wildlife Research Center, and Cape Cod National Seashore. 47 pp. Link

Sanchez-Cabeza, J.A., Ruiz-Fernández, A.C. 2012. ^{210}Pb sediment radiochronology: An integrated formulation and classification of dating models. Geochemica et Cosmochimica Acta 82:183-200. Link

Schmitt, J., Helms, A. 2017. South Slough NERR Sentinel Site Application Module 1 Plan. Charleston, OR: Slough National Estuarine Research Reserve, 42 pp.

Schomaker, M.C., Berry, R.M. 1981. Geodetic leveling (Vol. 55). Rockville, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, NOAA Manual NOS NGS 3. 224 pp. Link

Schultz, M.A., Janousek, C.N., Brophy, L.S., Schmitt, J., Bridgham, S.D. 2023. How management interacts with environmental drivers to control greenhouse gas fluxes from Pacific Northwest coastal wetlands. Biogeochemistry 165:165-190. Link

Scott, D.N. 2024. Widespread wood placement and regrading drive lateral connectivity and reworking of the channel and floodplain in a valley bottom reset to Stage-0. Geomorphology 446:108987. Link

Souza, T.D. 2022. A century of disturbance: How anthropogenic modification has affected sediment accumulation patterns in the Coos Estuary during the last 100 years. MS thesis, University of North Carolina at Chapel Hill, 50 pp. Link

Sprecher, S. 2000. Installing monitoring wells/piezometers in wetlands. WRAP Technical Notes Collection (ERDC TN-WRAP-00-02), U.S. Army Engineer Research and Development Center. Link

Stavert, A.R., Saunois, M., Canadell, J.G., Poulter, B., Jackson, R.B., Regnier, P., Lauerwald, R., Raymond, P.A., Allen, G.H., et al. 2022. Regional trends and drivers of the global methane budget. Global Change Biology 28:182–200. Link

Stewart-Oaten, A., Murdoch, W.W., Parker, K.R. 1986. Environmental Impact Assessment: “Pseudoreplication” in time? Ecology 67:929-940. Link

Suring, E., Burns, P., Constable, R.J., Lorion, C.M., Wiley, D.J. 2015. Salmonid Life Cycle Monitoring in Western Oregon streams, 2012-2014. Salem, OR: Oregon Department of Fish and Wildlife, Monitoring Program Report Number OPSW-ODFW-2015-2. Link

Takenaka, A., Inui, Y., Osawa, A. 1998. Measurement of three-dimensional structure of plants with a simple device and estimation of light capture or individual leaves. Functional Ecology 12:159-165. Link

Temmerman, S., Bouma, T.J., Govers, G., Wang, Z.B., De Vries, M.B., Herman, P.M.J. 2005. Impact of vegetation on flow routing and sedimentation patterns: Three-dimensional modeling for a tidal marsh. Journal of Geophysical Research 110:F04019. Link

Tian, H., Xu, R., Canadell, J.G., Thompson, R.L., Winiwarter, W., Suntharalingam, P., Davidson, E.A., Ciais, P., Jackson, R.B., Janssens-Maenhout, G., et al. 2020. A comprehensive quantification of global nitrous oxide sources and sinks. Nature 586:248–256. Link

Thiault, L., Kernaleguen, L., Osenberg, C.W., Claudet, J. 2017. Progressive-change BACIPS: A flexible approach for environmental impact assessment. Methods in Ecology and Evolution 8:288-296. Link

Thom, B.A., Jones, K.K., Kavanagh, P.S., Reis, K.E.M. 2000. Stream Habitat Conditions in Western Oregon, 1999. Portland, OR: Oregon Department of Fish and Wildlife, Monitoring Program Report Number OPSW-ODFW-2000-5. Link

Ursino, N., Silvestri, S., Marani, M. 2004. Subsurface flow and vegetation patterns in tidal environments. Water Resources Research 40:W05115. Link

United States Environmental Protection Agency (US EPA). 2013. National rivers and streams assessment 2008-2009: A collaborative survey. Washington, D.C.: Office of Wetlands, Oceans and Watersheds and Office of Research and Development, EPA/841/D-13/001. Link

Wagner R.J., Boulger Jr., R.W., Oblinger, C.J., Smith, B.A. 2006. Guidelines and standard procedures for continuous water-quality monitors - Station operation, record keeping, and data reporting: U.S. Geological Survey Techniques and Methods 1-D3, 51 pp. Link

Wender, B.W., Harrington, C.A., Tappeiner, J.C. 2004. Flower and fruit production of understory shrubs in Western Washington and Oregon. Northwest Science 78: 124-140. Link

Westfall, J.A., Coulston, J.W., Moisen, G.G., Andersen, H.-E. 2022. Sampling and estimation documentation for the Enhanced Forest Inventory and Analysis Program: 2022. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station, Gen. Tech. Rep. NRS-GTR-207, 129 pp. Link

The Wetlands Conservancy and JCWC. 2022. Field protocol for 2022 beaver surveys. Link

Williams, T., Janousek, C.N., McKeon, M.A., Diefenderfer, H.L., Cornu, C.E., Borde, A.B., Apple, J., Brophy, L.S., Norwood, M., Schultz, M.A., Bridgham, S.D. 2025. Methane and nitrous oxide fluxes from reference, restored, and disturbed estuarine wetlands in Pacific Northwest, USA. Ecological Applications 35:e70011. Link

Wilson, C.G., Matisoff, G., Whiting, P.J. 2007. The use of ^{7}Be and $^{210}Pb_{xs}$ to differentiate fine suspended sediment sources in South Slough, Oregon. Estuaries and Coasts 30:348-358. Link

8. Appendix A: Summary of existing pre-restoration data.

Abbreviations: WAS = Wasson; Ref = reference; Aq = aquatic; Terr = terrestrial. All SSNERR data is available upon request.

Parameter class	WAS data	Ref data	Parameter(s)	Year(s) collected	Location of data
Aq. fauna	Y	Y	Beaver activity	2020-24	SSNERR data
Aq. fauna	Y	Y	Coho spawning	2015/16-2016/17	SSNERR data
Aq. fauna	Y	Y	Coho presence (eDNA)	2023 (WAS), 2019, 2023 (Ref)	SSNERR data
Aq. fauna	Y	Y	Lamprey presence (eDNA)	2019	SSNERR data
Aq. fauna	Y	Y	Lamprey abundance	2023 (WAS), 2018-23 (Ref)	SSNERR data
Aq. fauna	Y	Y	Macroinvertebrates	2023-24	SSNERR data
Aq. habitat	Y	Y	Stream habitat	2010	ODFW; SSNERR data
Aq. habitat	y		Channel thalweg, cross sections	2023-24	SSNERR data
Benchmark	y	Y	Vertical control mark	2023 (WAS), 2016-24 (Ref)	SSNERR data
Elevation	y		Channel elevation	2016, 2024 (WAS)	SSNERR data
Elevation	y	Y	Marsh elevation	2004, 2016, 2023 (WAS &Ref), 2018-19, 2021-22 (Ref)	SSNERR data; Brophy 2005
GHG emissions		y	Dark CO_2, N_2O, CH_4 emissions	2017-18	Schultz et al. 2023
GHG emissions	y	y	Light/dark CO_2, N_2O, CH_4 emissions	2021-22	Janousek et al. (2025b)
Groundwater	y	Y	Groundwater depth	2004, 2019-24	SSNERR data; Brophy 2005
Groundwater	y	y	Groundwater salinity	2023-24 (WAS), 2020-2024 (Ref)	SSNERR data
Landscape	y	y	Habitat mapping	2016	CDMO
Landscape	y	Y	Vegetation mapping	2016, 2023-24 (WAS), 2023-24 (Ref)	SSNERR data
Landscape	y		Photo points	2020	SSNERR data
Sediment/soils		y	Grain size	2021	SSNERR data
Sediment/soils	y	y	Soil texture class	2004	Brophy 2005
Sediment/soils	y	y	Soil carbon and organic matter content, bulk density	2004, 2024 (WAS), 2004, 2021-22 (Ref)	Poppe et al. 2024, Brophy 2005
Sediment/soils	y	y	Soil pH	2004	Brophy 2005
Sediment/soils	y	y	Soil temperature	2020-2024	SSNERR data
Sediment/soils	y	y	Soil nutrients (nitrogen, phosphorus)	2004	Brophy 2005
Sediment/soils	y	y	Sediment accretion rates	2021, 2023 (WAS), 2016, 2019-24 (Ref)	SSNERR data
Sediment/soils		y	Net elevation change rates	2016-2024	SSNERR data
Terr. fauna	y	y	Bird presence	2015-16 (WAS), 2021, 2024 (both)	SSNERR data
Terr. fauna	y	y	Deer abundance (genotypes)	2024	SSNERR data
Terr. fauna	y	y	Wildlife species detections	2023-24 (WAS), 2022-24 (Ref)	SSNERR data
Terr. fauna	y	y	Salamanders	2024-25	SSNERR data
Vegetation	y	y	Emergent % cover by species	2004, 2017, 2020, 2023-24 (WAS), 2004, 2016-24 (Ref)	SSNERR data; Brophy 2005
Vegetation		y	Shrub species, stem density, DBH	2018, 2021	SSNERR data
Vegetation		y	Tree species, DBH, height, crown, canopy cover, woody debris, duff depth	2011-2024	SSNERR data; Link to USDA
Water quality	y	y	Stream dissolved oxygen	2024	SSNERR data
Water quality	y	y	Nutrients (PO_4, DIN, NO_2, NO_3, NH_4, SiO_4)	2023-24	SSNERR data
Water quality	y	y	Stream temperature	2010-11, 2015- 17, (WAS),2017-21(Ref), 2023- 24 (both)	SSNERR data
Water quality	y	y	Stream salinity/specific conductivity	2023-24 (both), 2020-21 (Ref)	SSNERR data
Water quality	y	y	Stream turbidity	2023-24 (WAS), 2017-19, 2023-24 (Ref)	SSNERR data
Water quantity	y	y	Water discharge	2023-24 (both), 1991-96, 2010- 15, 2017-19 (Ref)	SSNERR data
Water quantity		y	Water level	2010-15, 2017- 21, 2023-24, 2020-2022	SSNERR and OSU data