Restoring Tidal Swamps in the U.S. Pacific Northwest: Information for Restoration Practitioners

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May 2024

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ACKNOWLEDGMENTS AND APPRECIATIONS

The technical sections of this report excerpt and summarize the scientific work of co-author Laura Brophy. These sections also rely considerably on the work of Heida Diefenderfer (Pacific Northwest National Laboratories), to whom we are indebted.

We are grateful for the time and expertise of the following restoration practitioners who filled out the survey that forms the basis for this report. Tidal swamp restoration is a new field, and we appreciate their willingness to help others learn from their experiences:

- Jenny Baker, The Nature Conservancy
- Laura S. Brophy, Estuary Technical Group, Institute for Applied Ecology
- Catherine Dunn, The Nature Conservancy
- Kristi Foster, Tillamook Estuaries Partnership
- Evan Hayduk, The MidCoast Watersheds Council
- Greg Hood, Skagit River System Cooperative
- Tom Josephson, Columbia River Estuary Study Taskforce
- Amber Parmenter, The Nature Conservancy
- Jake Robinson, Swanson Ecological Services
- Ian Sinks, Columbia Land Trust
- Jason R. Smith, Columbia River Estuary Study Taskforce
- Dick Vander Schaaf, The Nature Conservancy
- Hunter White, Environmental Science Associates (ESA)
- Alice Yeates, South Slough National Estuary Research Reserve

The report was also improved through advice and guidance from the following researchers and members of the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) Steering Committee and Science and Data Committee, as well as staff from PMEP and the Pacific States Marine Fisheries Commission (PSMFC).

- Laura S. Brophy, Estuary Technical Group, Institute for Applied Ecology
- Heida Diefenderfer, Pacific Northwest National Laboratory
- Van Hare, PSMFC
- Dayv Lowry, NOAA Fisheries, West Coast Region, Protected Resources Division
- Bill Pinnix, United States Fish and Wildlife Service
- Kate Sherman, PSMFC
- Todd Zackey, The Tulalip Tribes

PMEP and PSMFC provided support.

We honor and recognize the numerous Indigenous Peoples on whose ancestral lands the projects featured in this report occurred.

Cover photo: Sitka spruce tidal swamp, Nehalem estuary, Oregon, USA. Photo by Laura S. Brophy, CC BY-NC 4.0.

Recommended citation: 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.

Sitka spruce tidal swamp, Nehalem estuary, Oregon, USA. Photo by Laura S. Brophy, CC BY-NC 4.0.

INTRODUCTION

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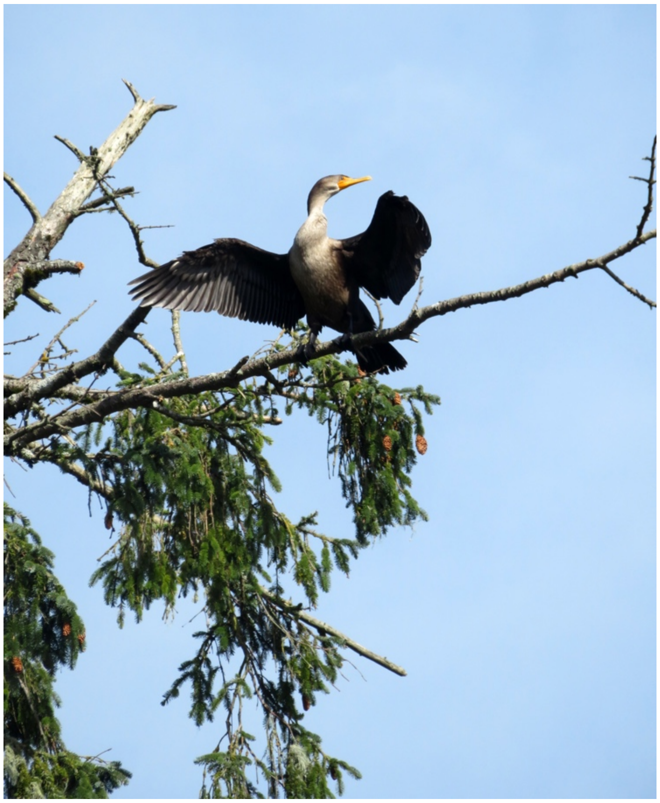
Tidal swamp restoration is a relatively new practice in the Pacific Northwest, and practitioners are actively developing its methods in the field (Diefenderfer et al., 2005). This report provides information on early efforts in the emerging field of tidal swamp restoration, including documentation of active tidal swamp restoration projects in the Pacific Northwest.

To support tidal swamp restoration practitioners, the Pacific States Marine Fisheries Commission (PSMFC) and the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) developed this report to provide an overview of important techniques and considerations when designing tidal swamp restoration. However, this report is not intended to be a guidance document, as guidance continues to be compiled by scientists, including many of the researchers cited herein and noted in the further reading section.

The report also documents information on current tidal restoration projects gleaned from an online survey of restoration project sponsors. The survey collected information on where restoration is occurring, the methods employed, what species are planted, monitoring parameters, and any available project outcomes to date. Restoration practitioners working on 14 restoration sites provided information. Please note that information from the Fisher Slough site in the Skagit Delta was collected after this report was in production, and therefore, some information from this site is presented differently than that of other sites. In particular, some of the graphics do not include information from the Fisher Sough site, and the section "Additional Project Information and Lessons Learned" presents information from that site in a different format. PMEP intends to continue distributing the practitioner survey (shown in the appendix) as more tidal swamp restoration sites are identified and new projects arise. PMEP will keep track of the success of these sites and disseminate information to assist the restoration community and improve the success of tidal swamp restoration along the U.S. West Coast.



Cormorant in a Sitka spruce tidal swamp, Siletz Bay, Oregon, USA. Photo by Fran Recht.

The following are key questions that we hope to answer by following the identified restoration projects over time:

- How does tidal swamp restoration success relate to site characteristics, such as elevation, hydrology, and salinity?
- Can tidal swamps be restored by controlling invasive species and replanting?
- What are effective methods for establishing vegetation (e.g., soil mounds or nurse logs)?
- Will restored areas come to resemble natural swamps in terms of supporting complex deep channels with abundant large woody debris (LWD), low tide refugia, and beaver presence?
- Will tidal swamp restoration sites persist?
- What parameters should be monitored to assess the effectiveness of tidal swamp restoration?

Sitka spruce – Oregon crabapple – black twinberry tidal swamp, Yaquina estuary, Oregon, USA.
Photo by Laura S. Brophy, CC BY-NC 4.0.

BACKGROUND

BACKGROUND

Tidal swamps are wetlands with vegetation dominated by woody plants (trees or shrubs) and wetland surface inundation driven by ocean tides. Tidal swamps were historically common in the Pacific Northwest but are now rare (Brophy, 2019). By contrast, tidal marshes—although also experiencing tidally-driven surface inundation—are dominated by nonwoody vegetation like sedges, reeds, rushes, and grasses. Two types of tidal swamps occur in the Pacific Northwest, distinguished by the extent and canopy height of woody vegetation present.

1. *Forested tidal wetlands,* also known as *tidal forests* or *forested tidal swamps*, are defined in the Coastal and Marine Ecological Classification Standard (CMECS) as having more than 10% tree cover (Federal Geographic Data Committee, 2012). In the Pacific Northwest, trees like Sitka spruce, Oregon crabapple, black cottonwood, Western red cedar, bitter cherry, red alder, and Oregon ash are common in tidal forested wetlands (Table 1).
2. *Scrub-shrub tidal wetlands*, also known as *shrub tidal swamps*, are dominated by woody vegetation less than 6 m (20 ft) tall with less than 10% tree cover, as defined in the CMECS (Federal Geographic Data Committee, 2012). Common shrubs in Pacific Northwest tidal swamps include several willow species, sweetgale, twinberry, red osier dogwood, cascara, salmonberry, wax myrtle, and others.

Sitka spruce tidal swamp, Siletz Bay, Oregon, USA. Photo by Fran Recht.

Regardless of type, tidal swamp salinities in the Pacific Northwest generally range from freshwater (salinity less than 0.5% PSU) to brackish. CMECS defines the upper limit of salinity for brackish scrub-shrub and forested tidal wetlands as 30 PSU (the same upper limit used in CMECS for all brackish wetlands; Federal Geographic Data Committee, 2012), but actual salinity tolerances for Pacific Northwest tidal swamps have not yet been rigorously determined. However, dry-season soil salinities up to 18 PSU have been documented in Pacific Northwest Sitka spruce swamps (Brophy et al., 2011), and the majority of Sitka spruce tidal swamps studied to date had dry-season water salinities in the lower mesohaline range, between 5 and 15 PSU (Brophy, 2009; Brophy et al., 2011, 2024). A combination of salinity and elevation (including the frequency of tidal flooding) appears to control the extent of tidal swamps: Tidal marsh predominates downstream or downslope, where higher salinities and/or more frequent tidal inundation prevail, but tidal swamp is dominant upstream or upslope under fresher and/or less-frequently-inundated conditions (Brophy et al., 2016).

Table 1. Plant and animal species commonly found in tidal swamps of the Pacific Northwest.

Common name	Scientific name	Common name	Scientific name
Native plant species			
Bitter cherry	*Prunus emarginata*	Red alder	*Alnus rubra*
Black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	Red osier dogwood	*Cornus sericea*
Black twinberry	*Lonicera involucrata*	Salmonberry	*Rubus spectabilis*
Cascara	*Rhamnus purshiana*	Scouler's willow	*Salix scouleriana*
Cattail	*Typha latifolia*	Shining or Pacific willow	*Salix lucida*
Douglas spirea (hardhack)	*Spiraea douglasii*	Sitka spruce	*Picea sitchensis*
Hooker's (or coast or dune) willow	*Salix hookeriana*	Sitka willow	*Salix sitchensis*
Lyngbye's sedge	*Carex lyngbyei*	Slough sedge	*Carex obnupta*
Ninebark	*Physocarpus capitatus*	Spikerush	*Eleocharis palustris*
Nodding beggars-ticks	*Bidens cernua*	Sweetgale (bog myrtle)	*Myrica gale*
Nootka rose	*Rosa nutkana*	Wapato	*Sagittaria latifolia*
Oregon ash	*Fraxinus latifolia*	Western red cedar	*Thuja plicata*
Oregon (Pacific) crabapple	*Malus fusca*	Western skunk cabbage	*Lysichiton americanus*
Pacific wax myrtle	*Myrica californica*		
Non-native and/or invasive plant species			
Buttonbush	*Cephalanthus occidentalis*	Knotweed	*Fallopia* spp. or *Persicaria wallichii*
Blackberry	*Rubus bifrons*	Purple loosestrife	*Lythrum salicaria*
Gorse	*Ulex europaeus*	Reed canarygrass	*Phalaris arundinacea*
English ivy	*Hedera helix*	Yellow flag iris	*Iris pseudacorus*
Native animal species			
Acorn woodpecker	*Melanerpes formicivorus*	Northern flicker	*Colaptes auratus*

Common name	Scientific name	Common name	Scientific name
Beaver	*Castor canadensis*	Pacific wren	*Troglodytes pacificus*
Black-capped chickadee	*Poecile atricapillus*	Pileated woodpecker	*Dryocopus pileatus*
Cedar waxwing	*Bombycilla cedrorum*	Red-breasted sapsucker	*Sphyrapicus ruber*
Coho salmon	*Oncorhynchus kisutch*	Red crossbill	*Loxia curvirostra*
Columbian black-tailed deer	*Odocoileus hemionus* ssp. *columbianus*	River otter	*Lontra canadensis*
Chinook salmon	*Oncorhynchus tshawytscha*	Roosevelt elk	*Cervus elaphus* ssp. *roosevelti*
Deer mouse (western)	*Peromyscus sonoriensis*	Song sparrow	*Melospiza melodia*
Downy woodpecker	*Picoides pubescens*	Steller's jay	*Cyanocitta stelleri*
Golden-crowned kinglet	*Regulus satrapa*	Swainson's thrush	*Catharus ustulatus*
Great blue heron	*Ardea herodias*	Tree swallow	*Tachycineta bicolor*
Hairy woodpecker	*Leuconotopicus villosus*	Vagrant shrew	*Sorex vagrans*
Hermit thrush	*Catharus guttatus*		

Importance of tidal wetlands

Tidal swamps and other wetland habitats provide energy-rich and abundant insect and amphipod populations for juvenile salmon foraging. Providing nutritious prey leads to higher salmon growth rates and longer stays in the estuary, resulting in higher adult survival rates (Davis et al., 2019; Greene et al., 2021). In the Nisqually Delta of the Salish Sea, Davis et al. (2019) found that tidal forested wetlands, like emergent marshes, offer early-life growth advantages for Chinook salmon. They found that salmon prey energy density was 46% to 86% higher in tidal freshwater forests than in other habitat types due to the consumption of energy-dense terrestrial adult insects and insect larvae from overhanging vegetation. These well-fed salmon had growth rates 0.5% higher in tidal forests than fish found in adjacent habitats, such as mudflats and nearshore intertidal areas (Davis et al., 2019). Similar studies conducted in the Columbia River estuary have linked estuary restoration (mostly of marshes) to increased habitat capacity, resulting in higher prey densities (among insects and amphipods) and higher juvenile growth rates (Bottom, n.d.; Diefenderfer et al., 2013). Increases in juvenile growth rates relate directly to survival (Jones et al., 2014). Jones et al. (2014) found that in Oregon's Salmon River, coho and Chinook salmon that resided longer in estuary habitats returned at disproportionately higher rates as adults than fish that did not use these habitats. Most importantly, the mosaic of habitats in the estuary increases the diversity and resilience of salmon life history (Bottom, n.d.; Davis et al., 2019; Greene et al., 2021; Woo et al., 2019). Greene et al. (2021) found that the energy density of the diets differed seasonally between wetland types throughout the rearing period. Riverine tidal swamps and, to a

Oregon crabapple swamp, Siletz Bay, Oregon, USA. Photo by Fran Recht.

lesser extent, estuarine tidal swamps were more beneficial early in the season when waters were colder. The more marine-influenced environments (estuarine emergent marsh) afforded higher growth potential as the season advanced and waters warmed.

Like other tidal wetlands, tidal swamps provide additional important ecosystem services. Both tidal forested wetlands and tidal shrub swamps provide fish and wildlife habitat, stabilize and capture sediment, improve water quality, dissipate flood waters, and sequester carbon.

Tidal swamps are also important to land animals and birds (Table 1). Animals found in tidal swamps include Roosevelt elk (*Cervus elaphus roosevelti*), river otter, beaver, Columbia black-tailed deer, and a host of small mammals and their predators (e.g., coyote [*Canis latrans*]; Callaway et al., 2012). In some tidal shrub swamp habitats, beaver dams and lodges have been documented in densities comparable to river habitats (Diefenderfer & Montgomery, 2009; Hood, 2012). Birds, including eagles, thrushes, sparrows, wrens, warblers, and woodpeckers, are also heavy users of tidal swamps (Johnson & Simenstad, 2015). Heron and egret species nest in tidal wetland trees (Callaway et al., 2012).

In addition to providing high-quality and high-quantity prey for salmonids and other native species, tidal forested swamp habitats, like their riparian forested counterparts upriver, provide additional ecosystem value by improving levels of dissolved oxygen, shading streams, providing cover for forage and juvenile fish, and helping to keep water temperatures cool (Buenau et al., 2023; Findlay & Fischer, 2013; Peterson et al., 2008).

Tidal swamps sequester carbon more than other habitat types (Brophy et al., 2018; Kauffman et al., 2020). By one estimate, forested tidal wetlands store between two and three times more carbon per acre than other estuarine habitats, although tidal shrub swamps remain understudied (Kauffman et al., 2020). A study of tidal wetland restoration's greenhouse gas sequestration potential estimated that forested tidal wetland restoration could yield 7.9 metric tons of CO_2 equivalent per acre in carbon benefits (Troost et al., 2021). In a follow-up scoping assessment of carbon offset financing in the Pacific Northwest, Crooks et al. (2020) found that forested tidal wetland restoration in low-salinity or freshwater tidal zones may offer positive carbon finance outcomes despite a higher potential for soil methane (CH_4) emissions because of the additional carbon storage in aboveground biomass (trees), which supplements these ecosystems' high soil carbon stocks. Methane emissions are currently under investigation (Williams et al., 2024). Restoring tidal swamps can help increase the ecosystem functions lost when they are impacted by sea level rise (Temmerman et al., 2013).

Loss of tidal swamps

Decades of research have documented extensive losses in tidal marshes, but tidal swamp loss has only recently been well-documented. Tidal swamps are characterized by lower-salinity waters and/or higher elevations than tidal marshes, making their conversion to other human uses easier and more productive. The proximity of tidal swamps to larger river systems was attractive to logging interests who used the rivers to transport logs downstream more easily to market. Tidal swamps were logged, cleared, filled, diked, drained, and blocked by tide gates (Brophy, 2019; Diefenderfer, 2007) to allow for agriculture, grazing, and development. Loss of tidal swamp habitat began during early European settlement (late 1700s) and continued with little to no documentation until wetland protection laws were enacted in the 1970s.

A study by the Columbia River Estuary Study Task Force found that tidal swamp habitat was the most severely impacted estuarine habitat in the Columbia River estuary, with a net loss of 23,000 acres, or 77% of total acreage, since 1870, primarily due to diking (Thomas, 1983). In the lower-elevation, brackish areas of the Columbia River estuary (Youngs Bay and Baker Bay), tidal swamps have been virtually eliminated (Youngs Bay: 96% loss; Baker Bay: 100% loss). Losses are just as severe for freshwater areas. Bottom et al. (2005) estimated an 88% loss of tidal swamp habitat in Grays Bay, 49% loss in Cathlamet Bay, and 80% loss for the upper estuary. A more recent study confirmed these losses, reporting a 75% loss in forested tidal wetland habitats in the Columbia River estuary (Marcoe & Pilson, 2017).

Until Brophy (2019) reported on the historical losses of forested, scrub-shrub, and emergent tidal wetlands on the Oregon coast, there was little understanding of comparative loss rates between different tidal wetland categories on the Oregon coast. Indeed, the many outreach efforts undertaken by Brophy for the Estuary Technical Group and PMEP have built broader awareness and interest in tidal swamps and their ecological value among both the public and the scientific community.

Brophy et al. (2019) estimated the historical extent of vegetated tidal wetlands along the U.S. West Coast using water level models and lidar-based elevation mapping. Vegetated tidal wetlands included low and high marsh areas (emergent wetlands), as well as tidal swamps (forested and scrub-shrub), ecosystems that are generally distributed along an elevation and salinity gradient. An indirect loss assessment method estimated how much of that habitat had been lost. For the 55 estuaries analyzed (which represented 97% of the total estuary area), the authors estimated a total of 735,000 ha (1.82 million acres) of vegetated tidal wetlands were present historically, but that 85% of that area has been lost (624,750 ha, or 1.54 million acres). The results varied by estuary, ranging from 1% to 98% loss. Each ecoregion defined by PMEP (Salish Sea, Pacific Northwest, Central California, and Southern California Bight) experienced tidal wetland losses ranging from 60% to 80% (Brophy et al., 2019).[1]

In a follow-up effort by PMEP, Brophy (2019) calculated the loss of vegetated tidal wetlands on Oregon's outer coast (not including the Columbia River). This report estimated that the historical tidal wetland area on the outer coast totaled 15,399 ha (38,052 acres), of which the majority (54.4%) was forested tidal swamp, 42.2% was tidal marsh, and 3.4% was shrub tidal swamp. Subsequent losses varied greatly by habitat type, with 95% loss (14,629 ha; 36,149 acres) of historical tidal forests and 96% loss of tidal shrub habitat. Thus, the loss of tidal swamp was much more severe than the loss of historical tidal marsh (59% loss). Brophy (2019) also found that most of the remaining tidal swamp habitats were small (less than 25 acres), dispersed, and fragmented.

Sitka spruce tidal swamp, Siuslaw estuary, Oregon, USA. Photo by Laura S. Brophy, CC BY-NC 4.0.

Tidal swamps and sea level rise

Climate change and associated sea level rise are anticipated to continue to affect these tidal swamp habitats. Projections made in 2022 by the National Oceanic and Atmospheric Administration (NOAA) provided median sea level rise estimates under intermediate, intermediate-high, and high climate change scenarios (Sweet et al., 2022). By 2100, the West Coast could experience a median sea level rise of 0.8 m (2.6 ft), 1.3 m (4.3 ft), or 1.8 m (5.9 ft), depending on the climate change scenario. By 2150, NOAA estimates potential median sea level rise for the West Coast of 1.6 m (5.25 ft), 2.3 m (7.5 ft), or 3.3 m (10.8 ft). As sea levels rise, tidal swamp persistence will likely require upslope migration (e.g., through seed dispersal) or novel establishment at higher elevations.

Available projections for sea level rise suggest that tidal swamps may only persist in their current locations or be restorable in their historical locations if sediment accretion keeps pace with rising waters (Brophy et al., 2011; Brophy & Ewald, 2017). For example, current tidal swamps may be converted to

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[1] Two video presentations by Laura S. Brophy provide accessible summaries of tidal swamp benefits and losses: *Little-Known Forests of the Tidelands: Oregon's Magnificent Tidal Swamps, Past and Present* (December 2020, https://youtu.be/3FUZX1ymjmw) and *Past, Present and Future of Tidal Wetlands in the Yaquina Bay Estuary* (February 2022, https://youtu.be/jpfm_COSQz4).

tidal marshes as sea levels rise, a phenomenon currently manifesting as “ghost forests” on the U.S. East Coast (Smart et al., 2020). Additionally, dikes, ditches, and tide gates cause subsidence (lowering) of swamp ground surfaces (Diefenderfer et al., 2008), making possible restoration sites identified today potentially inappropriate for restoration under future sea level rise scenarios.

Sediment accumulation has, in fact, been documented to be initially greater in tidal marsh restoration sites compared to sites in their natural state. In the Stillaguamish estuary in the Salish Sea, the restoration of tidal and riverine flooding was found to greatly enhance rates of sediment and carbon accumulation (Poppe & Rybczyk, 2021). The average sediment accretion rate of 1.57 cm/year was greater than the current rate for sea level rise (though expected to slow as the site attained the same elevation as the natural marshes). These sediment accretion rates were higher than those seen in the Walloskee-Youngs restoration site near Astoria, Oregon (Brophy & Ewald, 2017) and the Southern Flow Corridor in Tillamook, Oregon (Brophy et al., 2018) and the southern Salish Sea (Drexler et al., 2019). Ongoing studies of sediment and carbon accumulation in various restored tidal wetlands across California, Oregon, and Washington will help us understand controlling factors. One such study is the Mature Restoration Analysis (MAREA), funded by the National Estuarine Research Reserve System Science Collaborative and led by the South Slough Estuarine Research Reserve and Dr. Chris Janousek from Oregon State University. A final report is expected in 2024.

In 2017, the MidCoast Watersheds Council (MCWC) commissioned a study of all 23 major estuaries on the Oregon coast south of the Columbia River to identify where tidal wetlands would be able to persist under various projections for sea level rise (Brophy & Ewald, 2017). They mapped and prioritized the areas where elevations were appropriate for future tidal wetlands using an intermediate-high 4.7 ft (1.2 m) scenario for sea level rise for the year 2100. They prioritized landward migration zones (LMZs) for conservation and restoration based on five factors:

- the extent of the area at a 4.7-ft sea level rise,
- the extent of the area that would be available at an even higher sea level rise,
- ownership (public versus private),
- zoning, and
- development status.

Some areas identified as high priorities might be of appropriate elevation for tidal swamp restoration efforts.

Sitka spruce – Oregon crabapple – black twinberry tidal swamp, Nehalem estuary, Oregon, USA. Herbaceous species in foreground include slough sedge and Pacific lady fern. Photo by Laura S. Brophy, CC BY-NC 4.0.

TIDAL SWAMP RESTORATION METHODS AND CONSIDERATIONS

TIDAL SWAMP RESTORATION METHODS AND CONSIDERATIONS

Restoring tidal swamps will help increase the valuable ecosystem functions these habitats provide.

Though tidal swamp restoration is a relatively new field in the Pacific Northwest, previous efforts and focused research provide important insights into current restoration techniques. Critical considerations for tidal swamp restoration include the following six factors:

- the identification and monitoring of appropriate reference sites to assist restoration design and evaluation (Brophy, 2019; Roegner et al., 2008);
- vegetation planting and the use of elevated planting platforms (Diefenderfer et al., 2008);
- reed canarygrass control (Sinks et al., 2021);
- LWD placement and channel outlet design (for juvenile salmon passage; Diefenderfer et al., 2021; Diefenderfer & Montgomery, 2009; Hood, 2007);
- beaver reintroduction/conservation (Diefenderfer & Montgomery, 2009; Hood, 2012; Marten, 2022); and
- the monitoring of restoration implementation and effectiveness (Rice et al., 2005; Roegner et al., 2008; Thayer et al., 2005).

This section summarizes recommendations and lessons learned from recent swamp restoration projects. However, the restoration practitioner is advised to consult the cited publications and the restoration practitioners themselves to better understand the various considerations related to each method and approach.

Reference site selection and monitoring

When planning a new tidal swamp restoration project, it will be important to examine historical conditions and nearby intact reference sites to best understand the effects of topography and elevation on site characteristics and plant communities. It is important to remember that tidal swamp restoration may not be possible in the same locations that historically supported this habitat type. This is commonly the case where human activities and altered sediment dynamics have led to subsidence (a lowering of the wetland surface elevation), resulting in conditions that are too wet or too saline for the historically dominant species (Brophy et al., 2018; Diefenderfer et al., 2008, 2016).

Identifying and monitoring tidal swamp reference sites located near a planned restoration site supports informed restoration design. Monitoring data from intact tidal swamp reference sites is needed to separate the effects of restoration from general environmental changes when assessing restoration trajectories, as in a Before-After-Control-Impact (BACI) design (Stewart-Oaten et al., 1986) or Before-After-Reference-Restoration (BARR) design (Diefenderfer et al., 2011, 2016). To aid restoration practitioners, Brophy et al. (2011) gathered data from tidal swamp reference sites in Oregon and Washington. The following selected publications offer further information. As with any fieldwork, landowner permission must be obtained before entering any site.

Oregon reference sites

- Brophy et al. (2019) mapped tidal swamp and tidal marsh in each of the 15 major estuaries studied; subject to landowner access permission, these could potentially serve as reference sites.
- Brophy (2009) described and monitored multiple parameters at two tidal swamp reference sites: one in the Siuslaw estuary (mapped as Site S63 in Brophy, 2005) and one in the Yaquina estuary (Site Y28 in Brophy, 1999). Both sites are privately owned, and landowner permission would be required for access and further monitoring.
- Hoquarten Slough in Tillamook, Oregon, has also been identified as a potential site for field trips to view intact tidal swamps (by kayak, west of Highway 101). Tidal swamps along Hoquarten Slough could also serve as reference sites, subject to landowner access permission.

Washington reference sites

- Thomas (1983) documented extensive freshwater tidal swamps in the Columbia River, notably in Cathlamet Bay around Blind Slough and Prairie Channel. A number of these still remain; contact the Columbia Land Trust and the Lower Columbia Estuary Partnership for further information.

- Diefenderfer et al. (2008) and Diefenderfer and Montgomery (2009) identified and studied three tidal swamp reference sites on tributaries to Grays Bay (Secret River and Crooked Creek reference sites) and the Grays River (Kandoll Reference Site on Seal Slough).
- Crooks et al. (2014) identified Heron Point and Otter Island in the Snohomish River as potential reference sites. Physical and biological conditions at Otter Island, as well as several other Pacific Northwest forested tidal swamps, have been monitored in recent blue carbon research (e.g., Kauffman et al., 2020).

Sitka spruce tidal swamp, Siletz Bay, Oregon, USA. Photo by Fran Recht.

Vegetation planting and elevated planting platforms

Tidal swamp restoration typically involves planting woody vegetation. Sitka spruce is the most characteristic foundational species associated with Pacific Northwest tidal swamps (Franklin & Dyrness, 1973), particularly in brackish salinity zones, but many other native woody plants make up tidal swamp vegetation complexes (see Table 1). Woody plantings should be carefully planned since they are more expensive than some revegetation techniques (such as seeding) and, in some areas, are subject to the impacts of beaver browse. Planting design must be based on the physical characteristics of the restoration site. For example, soil moisture in tidal swamps tends to decrease with increased elevation (Diefenderfer et al., 2018),

Trees and shrubs growing on the platforms created by Sitka spruce roots, Yaquina Bay, Oregon, USA. Photo by Laura S. Brophy, CC BY-NC 4.0.

and salinity levels are a critical determinant of vegetation distribution (Borde et al., 2020). As a result, vegetation distribution closely aligns with elevation, making it critical to consider vertical position when designing planting plans for tidal swamp restoration sites (Borde et al., 2020; Diefenderfer et al., 2008, 2018). The subsidence of diked land is also a consideration when predicting elevations after restoration (Diefenderfer et al., 2008).

As Brophy (2009) stated, “Sitka spruce can be considered a ‘system engineer’ due to its elevated root platforms, which support a more aerobic environment above the saturated soils below.”

Nurse log placement and planting

By providing unique microhabitats of “moist, exposed, organic and mixed mineral soil-humus” environments, downed logs (or *nurse logs*; Harmon & Franklin, 1989) provide another platform for plant colonization and growth in tidal swamps (Gonor et al., 1988; Hood, 2007; McGee & Birmingham, 1997). Nurse logs also provide sites for plant growth above mean higher high water (MHHW), and nurse logs may originate locally or from upstream riparian and floodplain forests (Diefenderfer & Montgomery, 2009; Hood, 2007). These findings speak to the importance of whole-watershed restoration since upstream land use practices have created a deficit of large trees in these areas. In a current restoration practice, logs often need to be brought into the site (see the first photo in the upcoming series of three photos demonstrating how logs have been introduced to restoration sites).

Nurse logs can also replicate the elevated root platforms provided by mature Sitka spruce trees, which provide a more aerobic environment for plant growth (Brophy, 2009) in tidal swamps and provide sites for plant growth above MHHW (Hood, 2007). Elevated planting platforms may be particularly needed at subsided sites (Diefenderfer et al., 2018). Restoration practitioners can replicate the functions of elevated planting platforms at swamp restoration project sites by placing elevated cribs (see the second photo in the upcoming series) or logs as planting platforms (see the third photo). To expedite and replicate the seed regeneration functions of nurse logs, some practitioners drill holes in placed logs and plant or seed directly into the log (e.g., see the log crib in the second photo). Practitioners have also made chainsaw slots to facilitate root growth into the soil.

Sitka spruce saplings establishing on a fallen spruce tree, Yaquina Bay, Oregon, USA. Photo by Evan Hayduk, MCWC.

(1)

(2)

(3)

Current restoration practices that have brought logs into the site: (1) Logs placed in the tidal floodplain will move around with tides and floods until they become stabilized, when they may be able to serve as nurse logs. Yaquina estuary, Oregon, USA. Photo by Peter Vince, MCWC. (2) Log cribs planted with Sitka spruce seedlings. Photo by Jake Robinson. (3) Matt Ruwaldt, Partnership for the Umpqua Rivers, shows a Sitka spruce sapling planted in a nurse log. Photo by Laura S. Brophy, CC BY-NC 4.0.

Mound construction

Installing mounds as planting platforms can effectively mimic the topographic heterogeneity in unaltered tidal swamps. The construction of artificial mounds may help improve restoration effectiveness. For example, topographic mounds with functions similar to those provided by nurse logs may help woody plantings survive and outcompete invasive species, such as reed canarygrass, improving the chance of restoration success (Diefenderfer et al., 2018).

Diefenderfer et al. (2018) provided specific advice on the design of mounds, including the importance of the source and organic content of the mound material. They advised covering mounds with topsoil but noted that the source of the topsoil should be considered, as some topsoil contains weed seeds. They also noted that subsequent maintenance, including weed control, should be planned for some years after planting.

Mound graded to provide elevated topography in a restoration project. Siletz Bay, Oregon, USA. Photo by Fran Recht.

Reed canarygrass control and management

Reed canarygrass is a common and widespread invasive species found in swamp habitats in North America (Lavergne & Molofsky, 2004). The biology and ecology of reed canarygrass make it extremely competitive, in part because the plant’s dense roots and vigorous growth make native vegetation difficult to establish. Reed canarygrass is also difficult to eradicate. Its management is of critical importance for any tidal swamp restoration effort. Sinks et al. (2021) reviewed methods for controlling reed canarygrass in the Pacific Northwest by conducting a literature review, interviews with practitioners, and field observations. They looked at control methods that modify ecological conditions (e.g., shade, inundation, nutrients, competition) as well as active control methods (e.g., herbicide, mowing, burning, grazing) and combinations of different methods. They summarized seven key considerations for the removal and long-term management of reed canarygrass at tidal swamp restoration sites:

- Control reed canarygrass at the largest scale possible, even to the watershed scale.
- Combine multiple methods for multiple years. Reed canarygrass has been shown to return to pretreatment conditions within three years without continued control (Lavergne & Molofsky, 2004).
- Note that pre-restoration treatment is more cost-effective than post-restoration treatment.
- Plant or seed strong competitors to fill aboveground and belowground niches.
- Remember that woody species affect light differently as plants grow (e.g., *Salix lucida* and *Fraxinus latifolia* do not shade the understory at maturity).
- Consider the potential loss of high marsh resulting from control methods focused on establishing high and low elevations.
- Consider removing heavy nutrient sources at least one year in advance of construction.

Unfortunately, many projects do not have adequate funding for post-restoration maintenance and monitoring; therefore, controlling reed canarygrass during restoration activities is the most effective strategy to date (Sinks et al., 2021). Reed canarygrass control experiments are being conducted at the Kandoll Farm and Wallacut restoration project sites. They aim to inform future strategies for the Columbia Land Trust that can ideally be used for native vegetation restoration at larger scales (see the "Current Tidal Swamp Restoration Efforts" section for more information on these two projects).

Large woody debris (LWD) and channel design

LWD is ubiquitous in streams, wetlands, and estuaries in the Pacific Northwest and influences multiple ecosystem functions, including habitat formation, nutrient cycling, vegetation zoning, and hydrology (Gippel, 1995; Hood, 2007; Naiman et al., 2002; Simenstad et al., 2003). The hydraulic geometry of tidal swamps is similarly controlled by the accumulation of LWD (i.e., wood debris jams) that affect channel development, pool development, and flow dynamics (Diefenderfer & Montgomery, 2009). Diefenderfer and Montgomery (2009) found that when legacy channel networks are present, but LWD is no longer present, the results can include the loss of pools and microtopography, as well as diminished nutrient and sediment export. LWD also plays an outsized role in the success of nitrogen-fixing plants in tidal swamps by providing growth platforms and reducing stress from inundation (Hood, 2007).

Diefenderfer and Montgomery (2009) monitored the presence of large wood in three freshwater tidal swamp reference sites near Grays Bay, Washington, in the Columbia River estuary, documenting the role of LWD in channel and pool formation. They classified tidal forested wetland channels consistent with a forced step-pool channel type, similar to that used in stream classifications. They proposed that this new classification can be used to inform log placements for restoration designs.

As with many restoration techniques, site conditions must inform channel design (Diefenderfer et al., 2021). For example, diked sites are often characterized by lower land elevations resulting from subsidence over time (Diefenderfer et al., 2008; Elliott et al., 2016). Diefenderfer et al. (2021) developed models and classifications for channel network design from studies of tidal wetland channel networks in the Columbia River estuary. They advised using local reference sites, field surveys, and local environmental data when designing channel networks. They further recommended the "natural network paradigm" approach, which integrates environmental processes (e.g., sedimentation) with structural factors (e.g., LWD) to develop restoration designs unique to each location.

Beaver monitoring and reintroduction

Beaver were once widely present in riverine and estuarine systems, and these ecosystem engineers can strongly affect tidal swamps (Diefenderfer & Montgomery, 2009; Hood, 2012; Jones et al., 1994). Beavers can affect and alter habitat through ponding and inundation, channel formation, and sediment capture, thus enhancing fish habitat (Dittbrenner et al., 2022; Wohl, 2021). Beavers in tidal shrub swamp habitat play a role in providing predation cover and food sources for Chinook salmon and other fish in the Pacific Northwest (Hood, 2012; Pollock et al., 2004). Hood (2007) noted beavers' strong association with tidal shrub swamps and recommended a greater focus on restoring this habitat type for the benefit of beavers and Chinook salmon. However, he also noted that trees in these habitats, which beavers use to build their dams, are strongly associated with large nurse logs, which act as planting platforms, as noted in this report's previous sections on vegetation planting and LWD. Thus, tidal shrub swamps' continued long-term sustainability depends on continuing to recruit large wood from upstream areas.

Beaver reintroductions may help emulate historical conditions and may also contribute to the climate change resilience of wetlands (Dittbrenner et al., 2018). A beaver dam analog (BDA) is a technique used to mimic beavers' effects on habitat and attract beavers to recolonize areas (Bouwes et al., 2018; Weber et al., 2017). Both beaver reintroduction and BDA installation have provided benefits to fish, including increased habitat heterogeneity, prey production, and improved stream water quality (i.e., temperature; Bouwes et al., 2018; Kemp et al., 2012; Weber et al., 2017). However, Petro et al. (2015) evaluated the relocation of nuisance beavers in Oregon and found

American beaver. Photo courtesy of Rawpixel, public domain, CC0 1.0.

mixed results, mainly due to the high mortality of relocated animals and the inconsistency of dam construction behavior in surviving animals. But more passive methods can also help encourage beavers to occupy and build dams at restoration sites, including providing food and lodging and planting riparian vegetation (Pollock et al., 2023).

Petro et al. (2015) recommended defining clear measures of success (e.g., dam building) when reintroducing or relocating beaver to improve fish habitats. Regardless of whether restoration includes beaver reintroduction or BDAs, it is important to assess and monitor beaver presence at tidal swamp restoration sites, as they play an outsized role in hydrology and woody plant survival. Awareness of beaver presence can help inform the success or failure of restoration efforts and can aid in understanding monitoring results.

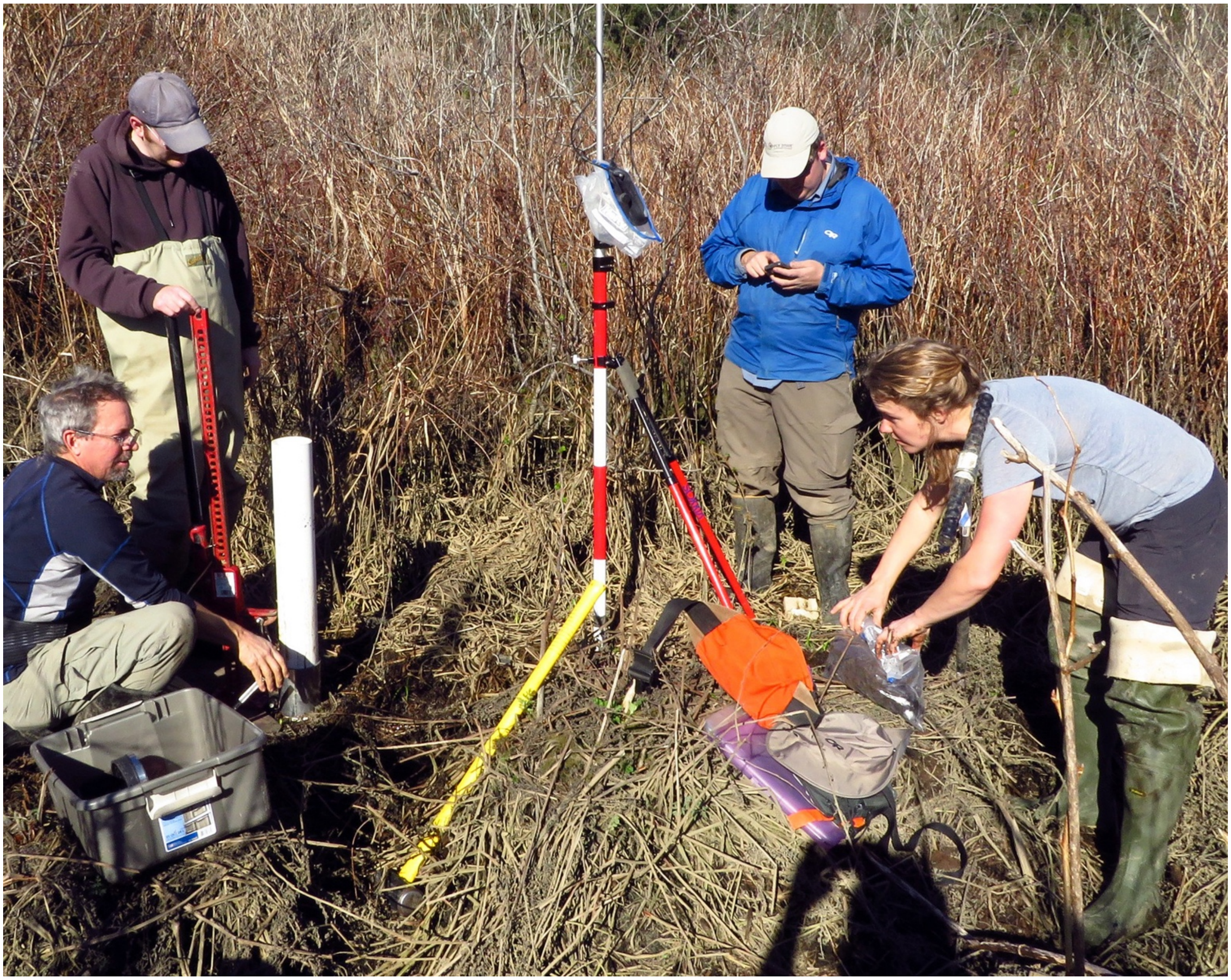
Restoration effectiveness monitoring

Since tidal swamp restoration efforts are relatively new, standardized effectiveness monitoring parameters have not yet been established, though they have been published as a NOAA Technical Memorandum for the Columbia River estuary (Roegner et al., 2008). At a minimum, any monitoring program should be established at one or more intact reference sites and at the restoration site, and the program should include measuring basic ecosystem drivers of tidal inundation and salinity (Brophy, 2009; Janousek et al., 2021). Brophy (2009) recommended that at least a year of monitoring occur at intact reference sites to provide baseline data for statistical analyses of restoration success. Monitoring parameters for tidal swamp restoration may mirror those of other wetland restorations, but parameters of particular importance at tidal swamp sites include shallow groundwater levels, channel and groundwater salinity, soil carbon, soil bulk density, and soil texture, as well as metrics such as vegetation and fish use, that provide insights into restoration success (Brophy, 2019). Past monitoring efforts can also provide helpful guidance. More complete recommendations and considerations for monitoring can be found in Appendix 11 of *Comparing Historical Losses of Forested, Scrub-Shrub, and Emergent Tidal Wetlands on the Oregon Coast, USA: A Paradigm Shift for Estuary Restoration and Conservation* (Brophy, 2019).

Brophy et al. (2011) monitored tidal swamps in Blind Slough (Columbia River) and Coal Creek (Nehalem River) between 2006 and 2009 to learn about the relationships between vegetation, surface water and groundwater levels, and channel water salinity. The effort resulted in a reference condition database for intact tidal swamps to which future practitioners could potentially contribute by monitoring the same parameters using similar methods. Brophy (2009) monitored similar parameters at two tidal swamp reference sites to establish baselines for restoration efforts in the Siuslaw Estuary (Table 2). Bailey (2011) monitored wetlands, including tidal swamps, in the Miami River restoration project. Parameters monitored included water level, water quality, soil characteristics, vegetation structure and composition, and fish and wildlife resources. Monitoring in 2006 provided a baseline from which to plan restoration work. Conditions were monitored for six years post-implementation (2011-2016), and a reduced suite of monitoring parameters has been sampled since 2016.

Table 2. Monitoring parameters (from Brophy, 2009).

Indicator category	Metric(s)
Controlling factors	
Tidal hydrology	Tidal inundation regime (frequency and duration of inundation)
Groundwater hydrology	Water table depth (monitored only at tidal swamp sites)
Topography	Wetland surface elevation
Water quality	Surface water salinity
Landscape setting	Habitat class interspersion Slope Aspect Geomorphic surface
Soils	Soil salinity (electrical conductivity) Organic matter content pH Soil texture
Ecosystem structure and function	
Vegetation	Plant community composition Woody plant density Tree basal area



Robert Wheatcroft, David Beugli, Michael Ewald, and Laura Brown collecting a deep core to measure soil carbon sequestration and sediment deposition rates. Oligohaline scrub-shrub tidal swamp, Columbia River estuary, Oregon, USA. Woody dominants include Douglas' spiraea, Nootka rose, and coast willow. Photo by Laura S. Brophy, CC BY-NC 4.0.

Roegner et al. (2008) suggested protocols for monitoring salmon habitat restoration projects in the Columbia River estuary. They provided protocols for "state of the science" data collection and analysis methods for landscape features, water quality, water fluctuations, sediment accretion, fish species composition, and other parameters (Table 3). Implementing these suggested protocols—developed to help determine the impacts of projects by the U.S. Army Corps of Engineers and restoration success—might be aspirational for most restoration practitioners depending on the funding and staffing available, although the authors recognized that more robust (and expensive) methods were available than those described. While not called out by Roegner et al. (2008), the presence of beaver or beaver signs should also be noted during monitoring efforts.

Table 3. Suggested monitoring parameters and sampling frequency for tidal swamps (from Roegner et al., 2008).

Indicator category	Monitoring metric	Collection method	Sampling frequency
Physical			
Hydrology	Surface water elevation	Data-logging instrument	Hourly
Water quality	Temperature	Data-logging instrument	Hourly
	Salinity		Hourly
Habitat	Landscape features	Photography, GIS	Annually
	Elevation	Ground survey	Annually
Biological			
Plants	Species composition	Ground survey	Annually
	Percent cover		
	Elevation		
	Planting success		
Fish	Species composition	Ground survey	Monthly/seasonally
	Size structure		
	Temporal presence		

Sitka spruce tidal swamp restoration site four years after planting, Siuslaw estuary, Oregon, USA. Photo by Laura S. Brophy, CC BY-NC 4.0. *Inset*: Seeds from cones collected in tidal swamps will be grown in a nursery before out-planting on a restoration site. Siletz estuary, Oregon, USA. Photo by Cheryl Horton, MCWC.

CURRENT TIDAL SWAMP RESTORATION EFFORTS

CURRENT TIDAL SWAMP RESTORATION EFFORTS

This section summarizes and highlights current tidal swamp restoration sites in Oregon and Washington. To obtain information about these sites, PSMFC distributed an online survey to restoration practitioners (see the appendix). To identify survey recipients, a review of tidal swamp and blue carbon studies was conducted, as were follow-up interviews with study authors. The survey was designed to collect information on tidal swamp restoration projects, including but not limited to project scale, scope, location, restoration techniques, vegetation species planted, and monitoring activities. PSMFC also archived swamp project design plans provided by select practitioners and survey participants. The tidal swamp restoration survey is still available online,[2] allowing for continued information collection on new tidal swamp restoration projects and existing projects not described herein.

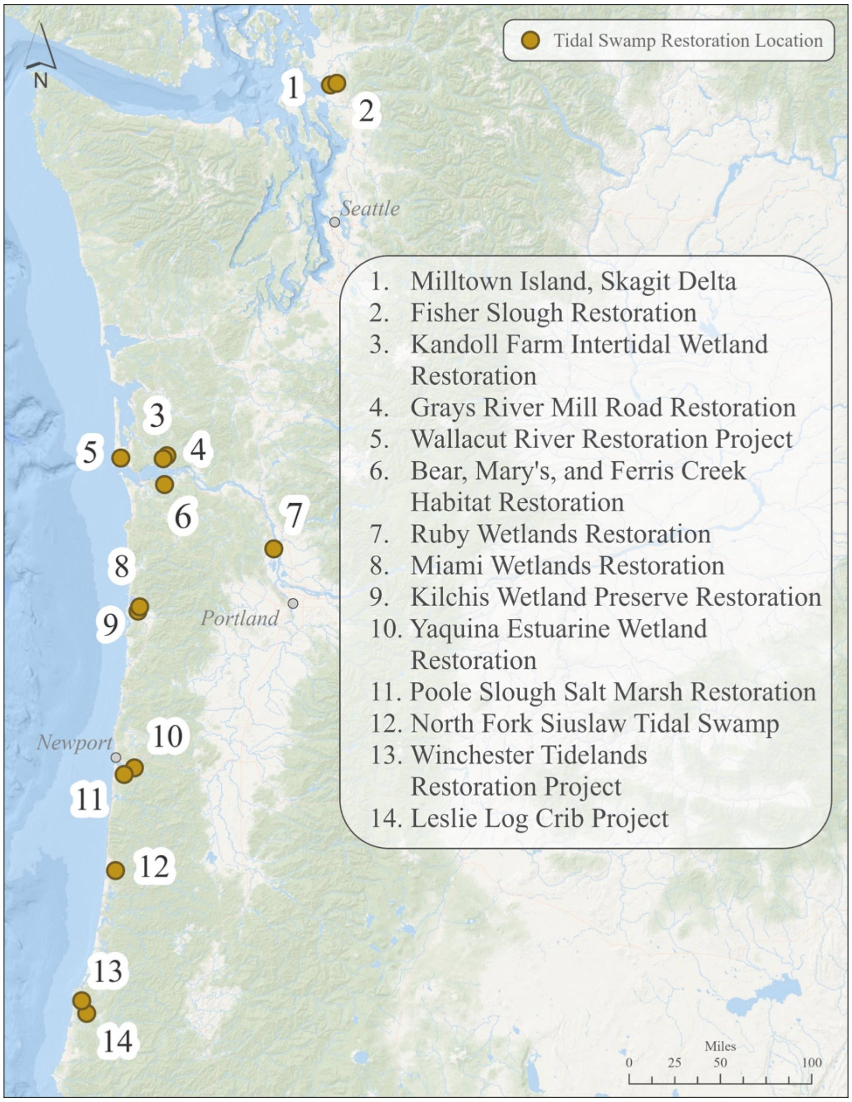


Figure 1. Locations of survey participant tidal swamp restoration project sites.

Practitioners identified their methods and if their approaches enhanced restoration effectiveness (at least in the short term). Most projects are too recent to establish whether the restoration sites will successfully develop swamps over the long term or will be sustainable and resilient compared to reference sites. The compiled survey results that follow are intended to provide baseline information on the scale, techniques, and follow-up monitoring currently incorporated into Pacific Northwest tidal swamp restoration projects.

Information was obtained for 14 projects with a tidal swamp restoration component: five sites in Washington and nine in Oregon (Figure 1). Twelve projects were completed, and two were in the design phase. It should be noted that in many cases, tidal swamp restoration was not the primary project focus. Instead, it was one component of a larger tidal marsh restoration project (Table 4).

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[2] Go to https://survey123.arcgis.com/share/0be91b8e841c4aa78e186864496feb8b for the online survey.

Table 4. Physical area and elevation of tidal swamp restoration projects.

Project no.	Project name	Organization	Completion date	Total project area (acres)	Tidal swamp area (acres)	Restored tidal swamp design elevations (NAVD88)
1	Milltown Island, Skagit Delta	Skagit River System Cooperative	In design	— — Not available — —		
2	Fisher Slough, Skagit Estuary	The Nature Conservancy	Oct 2011	60	5	7.5-11 ft
3	Kandoll Farm Intertidal Wetland Restoration	Columbia Land Trust	Jun 2016	163	163	Sitka spruce swamp > 12 ft; most below MHHW (MHHW = 8.82 ft)
4	Grays River Mill Road Restoration	Columbia Land Trust	Jun 2012	50	50	Sitka spruce swamp: 12 ft; mound placement < 12 ft
5	Wallacut River Restoration Project	Columbia Land Trust	Mar 2017	116	50	Not available
6	Bear, Mary's, and Ferris Creeks Habitat Restoration	Columbia River Estuary Study Taskforce	Oct 2018	64	64	Not available
7	Ruby Wetlands Restoration	Columbia River Estuary Study Taskforce	In design	122	10	7.5 ft
8	Miami Wetlands Restoration	The Nature Conservancy	Sep 2011	58	17	9 to 14 ft
9	Kilchis Wetland Preserve Restoration	The Nature Conservancy	Sep 2015	67	30	10 to 12 ft
10	Yaquina Estuarine Wetland Restoration	PSMFC & MCWC	Mar 2021	55	2.4	8.5 to 11 ft
11	Poole Slough Salt Marsh Restoration	MCWC	Aug 2021	2	1	Restoration plantings: 9 to 14 ft; LWD for nurse logs placed in LMZ areas (above current annual high tide)
12	North Fork Siuslaw Tidal Swamp	Estuary Technical Group, Institute for Applied Ecology	Mar 2008	12	12	Site not graded; site elevation ranges from 7 to 9 ft
13	Winchester Tidelands Restoration Project	South Slough National Estuarine Research Reserve	Sep 2002	12	1	Not available
14	Leslie Log Crib Project	Swanson Ecological Services	Feb 2017	0.5	0.5	Not available

Project site characteristics

For 12 of the 14 restoration sites, respondents provided information on the size (in acres) of the full restoration project (Figure 2) and specifically noted the size of the tidal swamp portion of the project (Figure 3). The swamp restoration site area ranged from less than 3 acres to 163 acres.

Respondents were asked to describe the site's pre-restoration vegetation (including invasive species). Before restoration, different sites had differing amounts of native woody vegetation. Willow, alder, spruce, and shrubs in surrounding riparian areas were most common. Invasive vegetation was predominant, with reed canarygrass abundant at most sites. Other common invasive species included various pasture grasses, blackberries, non-native cattail, knotweed, and gorse. One site had small, scattered populations of purple loosestrife, yellow flag iris, and ivy.

Design elevations[3]

Most respondents provided elevations relative to the North American Vertical Datum of 1988 (NAVD88), which varies in its relationship to tidal datums across the survey geography. For two sites, the design elevation for establishing swamps was 12 ft NAVD88 (Table 4). Two other sites used design elevations of 9-14 ft. Other design elevations used were 7.5 ft NAVD88, 8.5-11 ft, and 10-12 ft. One site had no grading, so there was no design elevation, but the respondent provided the site elevations relative to NAVD88. One respondent mentioned that large wood was placed above MHHW and in LMZ areas (potential future tidal wetland areas under sea level rise scenarios, as modeled by Brophy and Ewald [2017]). Respondents for one site mentioned that channel dimensions were informed by Pacific Northwest National Laboratory studies (Diefenderfer and other Columbia Estuary studies).

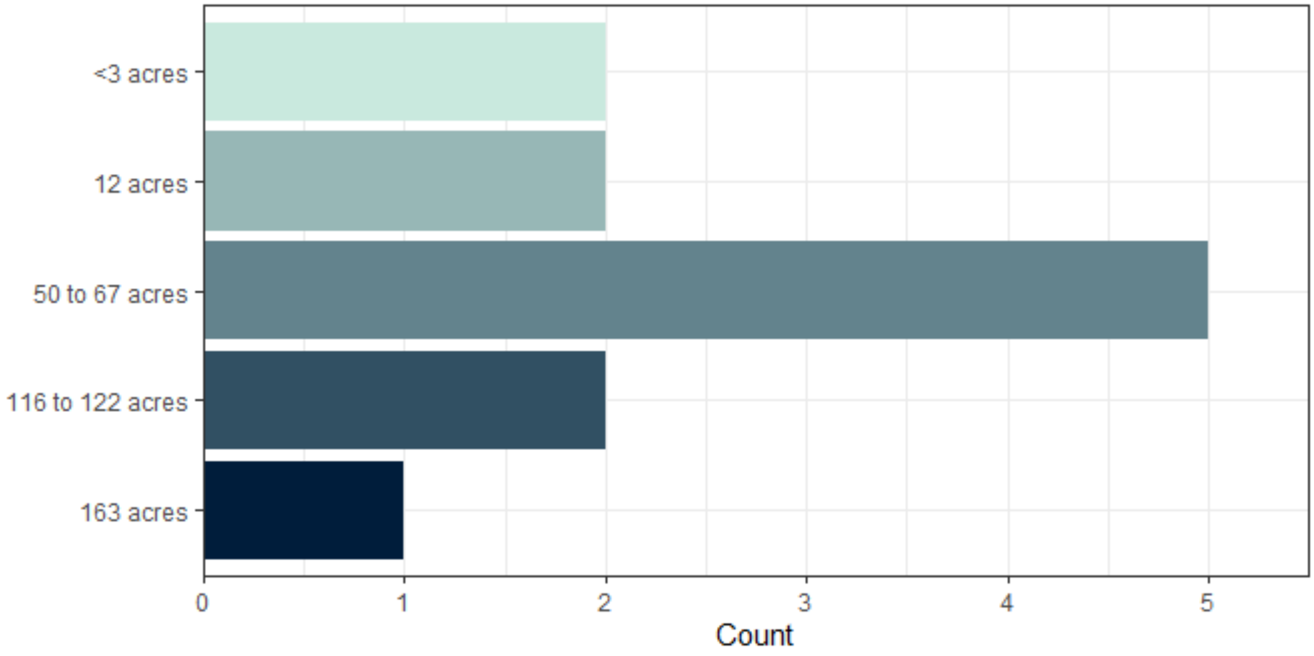

Figure 2. Total acreage of 12 restoration projects (that included some swamp restoration).

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[3] For comparison across geographic areas, design elevations should be expressed relative to tidal datums (such as "feet MLLW" or "meters MHHW") and/or standardized to tidal range (e.g., Z as used by Swanson et al. [2014]).

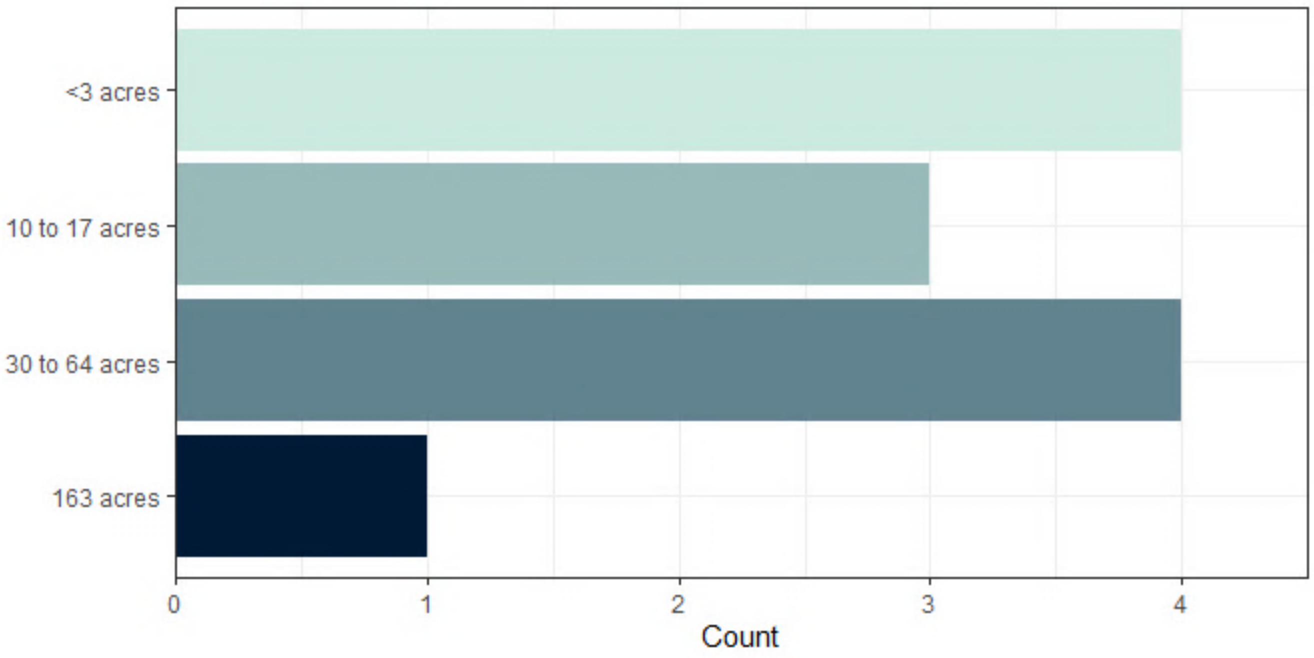

Figure 3. Total tidal swamp restoration acreage for 12 tidal swamp restoration projects.

Restoration techniques

Restoration practitioners were asked to identify which restoration techniques they used from a list provided in the survey. It included soil mounds, soil-filled cribs, nurse logs, LWD placement, and ”other.”

Most practitioners (62%) used a combination of techniques. Of the 13 sites that provided survey responses, five sites used just one technique, three sites used two, and five sites used three (Table 5).

Table 5. Restoration techniques used in tidal swamp restoration projects.

Project name	Organization	Restoration technique
One technique used		
Leslie Log Crib Project	Swanson Ecological Services	Soil-filled cribs
Miami Wetlands Restoration	The Nature Conservancy	LWD placement
Milltown Island, Skagit Delta	Skagit River System Cooperative	Soil mounds
Grays River Mill Road Restoration	Columbia Land Trust	Soil mounds
North Fork Siuslaw Tidal Swamp	Institute for Applied Ecology, Estuary Technical Group	LWD placement
Two techniques used		
Poole Slough Salt Marsh Restoration	MCWC	Nurse logs, LWD placement
Winchester Tidelands Restoration Project	South Slough National Estuarine Research Reserve	Soil mounds, LWD placement
Kilchis Wetland Preserve Restoration	The Nature Conservancy	Soil mounds, LWD placement

Project name	Organization	Restoration technique
Three techniques used		
Bear, Mary's, and Ferris Creeks Habitat Restoration	Columbia River Estuary Study Taskforce	Soil mounds, LWD placement, other
Yaquina Estuarine Wetland Restoration	PSMFC & MCWC	Soil mounds, LWD placement, other
Wallacut River Restoration Project	Columbia Land Trust	Soil mounds, LWD placement, other
Ruby Wetlands Restoration	Columbia River Estuary Study Taskforce	Soil mounds, LWD placement, other
Kandoll Farm Intertidal Wetland Restoration	Columbia Land Trust	Soil mounds, nurse logs, LWD placement

The use of soil mounds and LWD placement were the most frequently reported techniques. All other methods were used less than half as often as either of these techniques (Figure 4). "Other" techniques were general techniques not specific to swamp restoration (e.g., dike removal, ditch filling). Responses from restoration practitioners showed that the techniques currently used are consistent with recommendations from the available literature concerning the use of mounds, control of invasive reed canarygrass, and channel outlet design (for juvenile salmon passage; Diefenderfer et al., 2018, 2021).

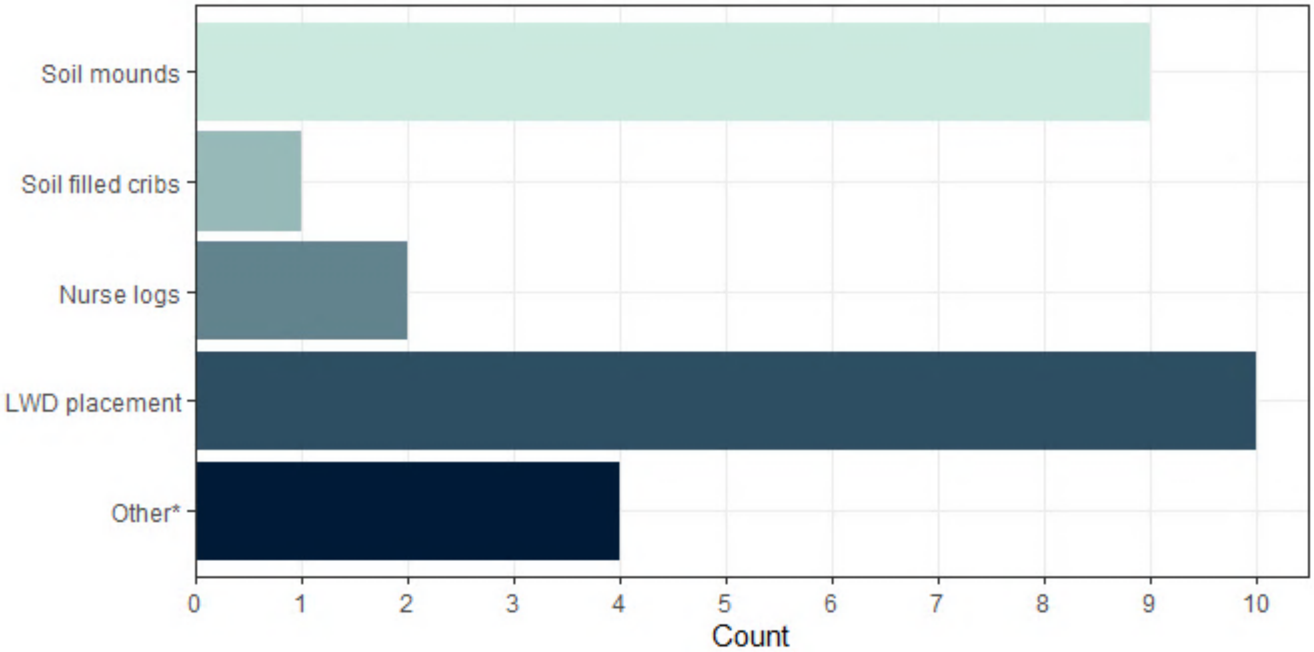

Figure 4. Tidal swamp restoration techniques and the number of projects that used it.

Restoration plantings

All respondents provided information on the species planted at the 14 restoration sites. Roughly half (six of 13) planted two to five species, while in eight of the 14 projects, six or more species were planted (Figure 5). Three projects planted 13 species. "Other" species planted included sword fern, a wetland forb-and-grass seed mix, evergreen huckleberry, and western hemlock.

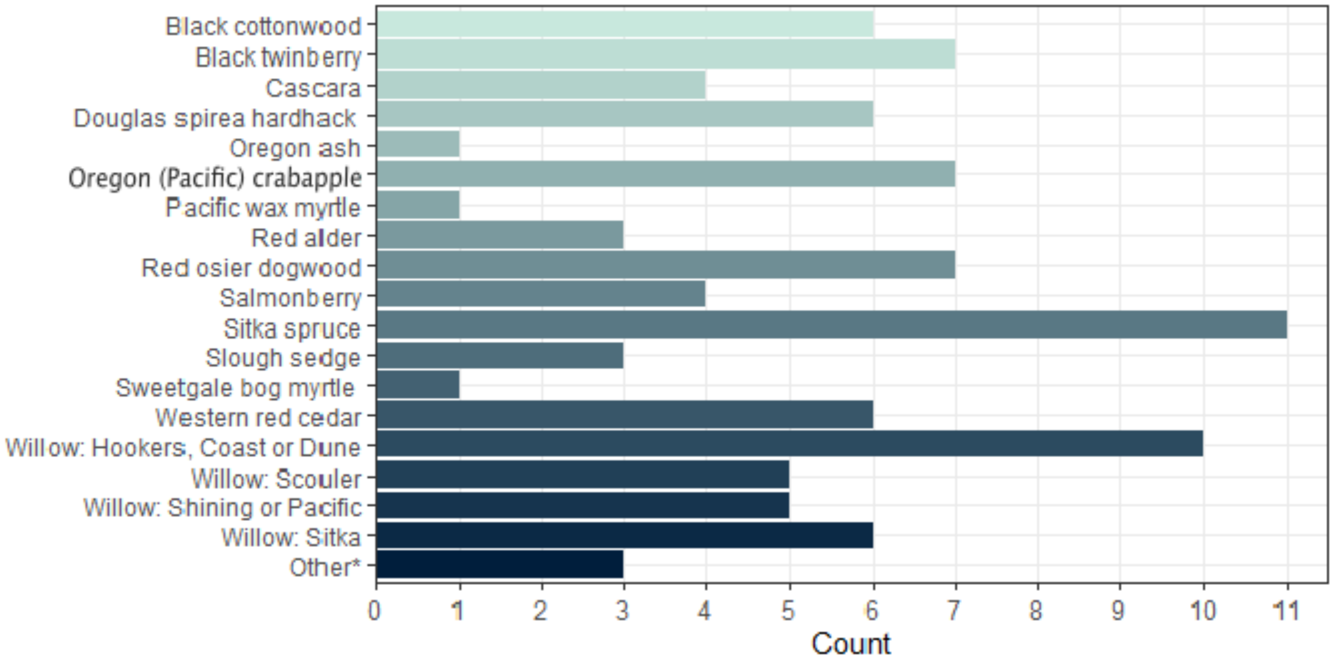

Figure 5. Species planted and the number of restoration sites where they were planted.

Restoration and reference site monitoring

All survey respondents provided information on the number and kind of post-restoration monitoring parameters tracked to determine project success (Figure 6). The most frequently tracked parameter was plantings survival, followed by the as-built elevation survey. Most respondents also monitored channel width, water temperature, inundation frequency, and vegetation cover (including reed canarygrass).

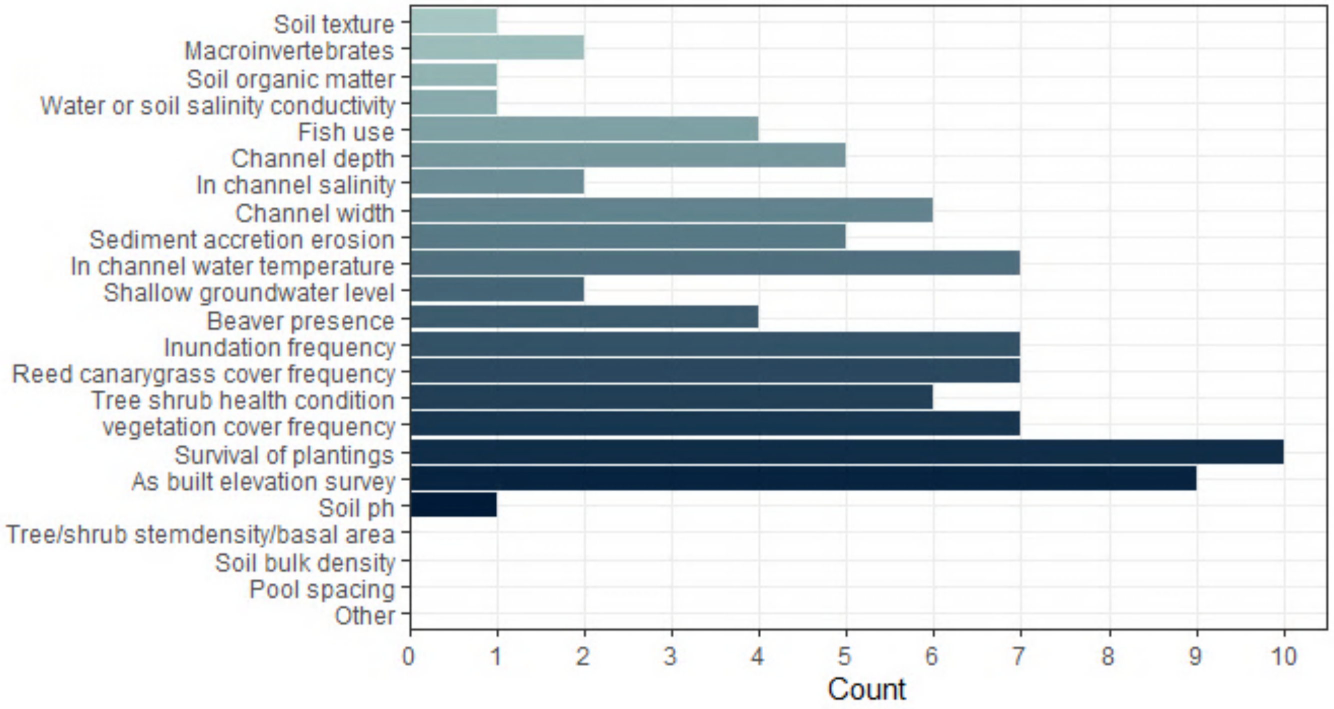

Figure 6. Monitoring parameters and the number of restoration projects that tracked them.

Reference sites

Most tidal swamp restoration projects used nearby reference sites to help inform restoration project design considerations (Figure 7). Reference sites were surveyed for a dominant plant cover and the presence or absence of beavers and LWD. Eight respondents noted specific dominant plants at reference sites: Sitka spruce (seven sites), willow species (four sites), and black twinberry (three sites). Other common co-occurring plant species included Pacific crabapple, alder, Pacific ninebark, dogwood, salmonberry, Douglas spirea, rose species, and Lyngbye's sedge. One respondent noted wapato, spikerush, nodding beggars-ticks, and reed canarygrass as dominants at their reference site.

Eleven respondents noted whether beavers were present at the reference site and whether their reference sites included large wood and pools (Figure 7). Seven reference sites had beavers at their reference sites, three respondents did not know whether beavers were present at their reference site, and one reference site did not have beavers. Nine reference sites had large wood and pools. For the two other reference sites, respondents did not note whether large wood and pools were present.

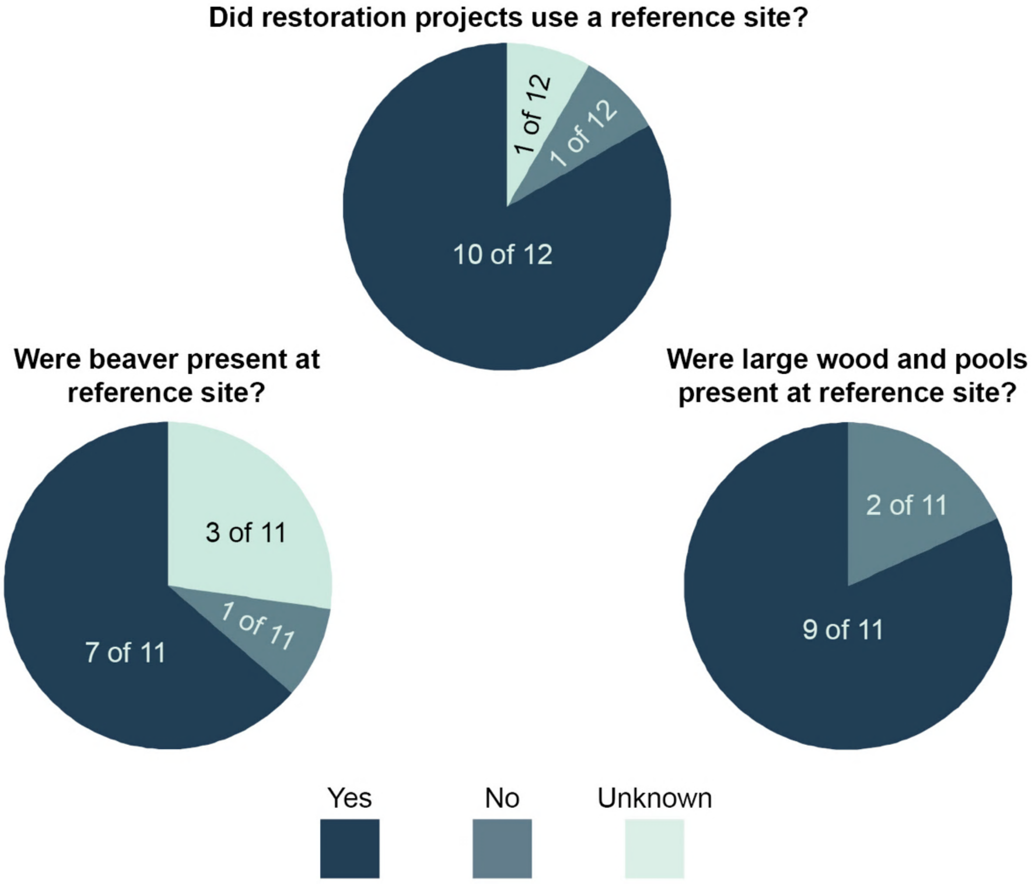

Figure 7. Select reference site metrics for restoration projects.

Additional project information and lessons learned

Survey respondents provided the following summaries in response to requests for final thoughts or ideas they wanted to share. Their answers highlight details of their future plans, methodological considerations, project outcomes, and lessons learned for eight of the projects covered in this report.

Kandoll Farm Intertidal Wetland Restoration, Columbia Land Trust

Project 3 in Figure 1

"The second phase of this 163-acre project was initiated in 2016. BDAs[4] were constructed but have not been utilized by beavers; however, beavers are utilizing the spaces between mounds. Revegetation work is ongoing. A reed canarygrass experiment is ongoing and is providing good direction to control reed canarygrass and restore marsh vegetation at scale. Additional monitoring information is available as needed. Channels are generally stable. Installed LWD is stable, but interstitial material has been lost from tidal forces. Fish presence has been documented, but monitoring is limited, and sediment accretion is mixed, depending on year and location. Beavers have focused on removing spruce trees from mounds on the interior of the site, presumably in favor of willow and other deciduous species. Subsidence recovery will require a long time period and may not keep pace with SLR [sea level rise]. The Pacific Northwest National Laboratory is doing blue carbon work on one of the reference sites and has preliminary findings regarding carbon stocks in these systems."

Fisher Slough, Skagit Estuary

Project 2 in Figure 1

The Fisher Slough Tidal Marsh Restoration project restored approximately 60 acres of freshwater tidal wetland habitat on formerly diked farmland. Five of these acres were tidal swamp; the rest were tidal marsh. The project was completed in October 2011, and the restored habitat is critical to Chinook salmon, a threatened species listed under the Endangered Species Act. The restoration project was designed to achieve substantial habitat and fish passage benefits while simultaneously increasing flood storage, improving drainage, and updating old infrastructure for the adjacent agricultural community within the Skagit River Delta. A portion of the site, where elevations are higher, was planted with willow and other native trees and shrubs. More information about the project can be found at https://salishsearestoration.org/wiki/Fisher_Slough_Restoration.

Grays River Mill Road Restoration, Columbia Land Trust

Project 4 in Figure 1

"Large wood was excavated during channel construction (and replaced within the channel). Large amounts of wood were found to be buried on the site."

Wallacut River Restoration Project, Columbia Land Trust

Project 5 in Figure 1

"The primary restoration strategy on this site was to restore tidal connectivity, excavate pilot channels, control weeds, and restore native vegetation. The Wallacut is an altered watershed, given the tide gates located upstream of the project, which limit tidal inflow into a significant portion of the watershed, impacting channel dynamics within the project reach. Also, the project is located on the north side of the Columbia River estuary, where prevailing storm winds push LWD into the Wallacut, often in large rafts, but the wood does not persist, as it eventually drifts out before settling or being entrained. A reed canarygrass control experiment was started at this site in 2022."

Ruby Wetlands Restoration, Columbia River Estuary Study Task Force

Project 7 in Figure 1

"The Columbia River Estuary Study Taskforce has utilized the restoration technique of lowering marsh plain elevations at numerous restoration projects along the Lower Columbia River. The ability to remove invasive reed canarygrass and prolong inundation in freshwater wetlands has led to more extensive areas of native emergent plant communities, which has reduced the need for herbicide treatment and ongoing vegetation maintenance."

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[4] BDAs, or beaver dam analogs, are human-made structures designed to mimic the form and function of a natural beaver dam and, in most cases, to promote beaver reestablishment.

Miami Wetlands Restoration, The Nature Conservancy

Project 8 in Figure 1

“This project ended up digging out a borrow pit to get more material to fill ditches. This may not be necessary when tidal channels are designed to excavate sufficient volume to fill ditches. However, the borrow pit has formed a nice seasonal pond feature that provides habitat value. It might be worth considering in your designs, even if the material is extra and just used to create hummocks. Additionally, beaver really wiped out the initial willow planting near newly excavated tidal channels before the willows could establish roots. Later, Tillamook Estuary Partnership’s planting crew successfully experimented with planting larger diameter willows (2") that fared better.”

Yaquina Estuarine Wetland Restoration, PSMFC/MCWC

Project 10 in Figure 1

“The Hooker’s willow was not successful when planted as stakes. This may be due to the soil at the main planting area being of such poor quality (muck from the bottom of the new dike breach channel), as well as heat stress. Crabapple was planted as both bare-root and potted stock; it’ll be interesting to see if one technique is more successful than the other. Spruce was planted as bare-root; the Douglas spirea and black twinberry were planted as potted stock. Dense mats of invasive creeping bentgrass are present but are likely to decline (Brophy observation) over time due to shading or competition from taller plants, such as tufted hairgrass (*Deschampsia cespitosa*) as tidal inundation occurs.

“We have found (not only in tidal sites) that to control reed canarygrass, the best approach is to plant fast-growing shrubs and trees, as reed canarygrass is intolerant of year-round shade. We also find that scalping during a restoration project is a good approach, scalping down 4-18″ depending on how deep rhizomes are found. Burying at the bottom of ditches to be filled is one strategy, but it can be tricky because if it is not deep enough, it may re-sprout. Also, since it is heavy in organic material, it will decompose, and you have to over-fill the ditch (6-12″ at least) to account for that settling. At Five Mile Bell, USFS [the U.S. Forest Service] piled reed canarygrass scalped material and covered [it] with tarps/cloth to compost it. In other sites, we don’t have ditches to fill; we pack the material against the toe slope, hopefully at a higher elevation where it is too dry for the rhizomes to re-sprout and where shade from native trees and shrubs can create a canopy over it to shade it out.”

Poole Slough Salt Marsh Restoration, MCWC

Project 11 in Figure 1

“The LWD placement in reed canarygrass in the landward migration zone [LMZ] (area that under sea level rise will become of proper elevation for tidal wetlands) was done as a pilot effort; this will inform future work. To try to establish spruce on the nurse logs, holes were drilled in the logs with a paddle bit (trying to use natural depression spots on the log where possible). The holes were filled with a mix of spruce seeds collected from within tidal swamps and local soil materials (mud/sand); no potting soil was used. Some of the holes were then covered with mud and dead grass to provide a little cover and to ensure soil contact for the seed. No bare-root or potted plants were used on the nurse logs as in other areas. We’ve experimented with that and have not had good survival.”

Winchester Tidelands Restoration Project, South Slough National Estuarine Research Reserve

Project 13 in Figure 1

“South Slough National Estuarine Research Reserve is planning more tidal swamp restoration in an adjacent drainage and are planning on using nurse cribs.”

John Christy conducting site reconnaissance at a Sitka spruce tidal swamp, Columbia River estuary, Oregon, USA. Yellow flowering plants in foreground are skunk cabbage. Photo by Laura S. Brophy, CC BY-NC .4.0.

DISCUSSION

DISCUSSION

Tidal swamps have undergone disproportionate losses compared to tidal marshes. Despite the research to date, significant gaps remain in understanding the effects of these losses and how best to restore these important habitats. Sea level rise presents a challenge to both the restoration and conservation of tidal swamps, as described earlier (Janousek et al., 2016). Fuller (2018) investigated tidal marsh vegetation mortality at a restoration site in the Stillaguamish estuary (Salish Sea) that was likely related to climate-change-induced alterations in freshwater inflows, and impacts of this type could also affect tidal swamps.

Brophy (2019) described several challenges related to physical conditions, including elevation loss (subsidence), soil compaction, and channel system alterations due to diking, ditching, and agricultural use. Invasive species such as reed canarygrass often pose a challenge to tidal swamp restoration in the Pacific Northwest (Diefenderfer et al., 2018; Sinks et al., 2021). Herbivory is a constant challenge when attempting to establish woody plants in tidal wetland restoration sites (Marten, 2022; Wasson et al., 2021). Although this report cannot list all challenges facing tidal swamp restoration, it has described practical approaches restoration practitioners use to address some of these issues.

Though the field of tidal swamp restoration is relatively young, the current body of practice, evidence, and documentation is quickly coalescing around science- and site-based best practices. This report provides some preliminary information that can be supplemented in the future as these projects are revisited and new projects are added. As such, it will be important for future restoration projects to use the online survey described herein to document and share lessons learned during all restoration projects. Even more valuable, restoration projects can be opportunities to systematically test new methods while contributing to the scientific literature on tidal swamp ecology and restoration.

Broadly, it is important that all tidal swamp restoration projects identify reference sites and incorporate restoration effectiveness monitoring from the outset. Furthermore, it is important that future tidal swamp restoration monitoring efforts align their monitoring parameters as much as possible with existing data from past projects. Regardless of the project, it is essential to consider the full suite of conditions at the restoration site (salinity, hydrology, invasive species, elevation, beaver interactions, etc.). Finally, it is important for restoration practitioners to identify areas where tidal wetlands may persist under future climate change scenarios and prioritize these LMZs for future restoration efforts (Brophy & Ewald, 2017).

PMEP supported this report to further its commitment to effectively restoring estuarine fish habitats along the U.S. West Coast. PMEP encourages practitioners of new tidal swamp restoration projects to document their site planning, restoration methods, and effectiveness monitoring and to share their results with PMEP.

REFERENCES

Bailey, S. J. (2011). *Miami wetlands enhancement project: Baseline monitoring report*. Tillamook Estuaries Partnership.

Borde, A. B., Diefenderfer, H. L., Cullinan, V. I., Zimmerman, S. A., & Thom, R. M.. (2020). Ecohydrology of wetland plant communities along an estuarine to tidal river gradient. *Ecosphere 11*(9), Article e03185. https://doi.org/10.1002/ecs2.3185

Bottom, D. (n.d.). *Restoring the River Salmon: Diversity and Resilience* [Web journal; Part 2]. Sitka Center for Art and Ecology. https://www.sitkacenter.org/journal/restoring-the-river-salmon-life-history-diversity-and-resilience

Bottom, D. L., Jones, K. K., Cornwell, T. J., Gray, A., & Simenstad, C. A. (2005). Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). *Estuarine, Coastal and Shelf Science*, *64*(1 SPEC. ISS.), 79–93. https://doi.org/10.1016/j.ecss.2005.02.008

Bouwes, N., Weber, N., Jordan, C. E., Saunders, W. C., Tattam, I. A., Volk, C., Wheaton, J. M., & Pollock, M. M. (2018). Correction: corrigendum: ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Scientific Reports* (8), Article 46995. https://doi.org/10.1038/srep46995

Brophy, L. S. (1999). *Yaquina and Alsea river basins estuarine wetland site prioritization project* [Final report; prepared for the MidCoast Watersheds Council, Newport, Oregon]. Green Point Consulting. https://doi.org/10.13140/RG.2.2.26654.20803

Brophy, L. S. (2005). *Tidal wetland prioritization for the Siuslaw River estuary* [Prepared for the Siuslaw Watershed Council, Mapleton, Oregon]. Green Point Consulting. https://doi.org/10.13140/RG.2.2.11561.52320/1

Brophy, L. S. (2009). *Effectiveness monitoring at tidal wetland restoration and reference sites in the Siuslaw River estuary: A tidal swamp focus* [Final report; prepared for Ecotrust, Portland, Oregon]. Green Point Consulting. http://dx.doi.org/10.13140/RG.2.2.32997.52964

Brophy, L. S. (2019). *Comparing historical losses of forested, scrub-shrub, and emergent tidal wetlands on the Oregon coast, USA: A paradigm shift for estuary restoration and conservation* [Prepared for the Pacific States Marine Fisheries Commission and the Pacific Marine and Estuarine Fish Habitat Partnership]. Institute for Applied Ecology, Estuary Technical Group. https://doi.org/10.13140/RG.2.2.25732.68481

Brophy, L. S., Borde, A. B., Cornu, C. E., Diefenderfer, H. L., & Janousek, C. N. (2024, March 5–7). *Perspectives on Pacific Northwest tidal forested wetlands: Historical extent, current conditions, and future threats* [Conference presentation]. Forested Wetlands of the Upper Estuary, Charleston, SC, United States. https://www.scseagrant.org/forested-wetlands-conference/

Brophy, L. S., Brown, L. A., & Ewald, M. J. (2016, April 7). *What makes a tidal wetland work? Emerging themes in monitoring the controlling factors that drive tidal wetland functions* [Conference presentation]. Society for Ecological Restoration - Northwest Conference, Portland, Oregon, United States. Institute for Applied Ecology, Estuary Technical Group.

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 tidal wetlands of Oregon, USA* [Amended final report; prepared for the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)]. Institute for Applied Ecology, Estuary Technical Group. https://doi.org/10.13140/RG.2.2.12864.87046

Brophy, L. S., & Ewald, M. J. (2017). *Modeling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future* [Prepared for MidCoast Watersheds Council, Newport, Oregon]. Institute for Applied Ecology, Estuary Technical Group. https://doi.org/10.13140/RG.2.2.19021.79845

Brophy, L. S., Greene, C. M., Hare, V. C., Holycross, B., Lanier, A., Heady, W. N., O'Connor, K., Imaki, H., Haddad, T., & 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*(8), 1–34, Article e0218558. https://doi.org/10.1371/journal.pone.0218558

Brophy, L. S., Peck, E. K., Bailey, S. J., Cornu, C. E., Wheatcroft, R. A., Brown, L. A., & Ewald, M. J. (2018). *Southern Flow Corridor effectiveness monitoring, 2015-2017: Sediment accretion and blue carbon* [Prepared for Tillamook County and the Tillamook Estuaries Partnership, Tillamook, Oregon, USA]. http://dx.doi.org/10.13140/RG.2.2.28592.38405

Buenau, K. E., Diefenderfer, H. L., Borde, A. B, & McKeon, M. (2023). *Tidal-hydrological dynamics of water temperature across freshwater forested wetlands on the Northeastern Pacific Coast* [Manuscript submitted for publication]. Pacific Northwest National Laboratory and University of Washington.

Callaway, J. C., Borde, A. B., Diefenderfer, H. L., Parker, V. T., Rybczyk, J. M., & Thom, R. M. (2012). Pacific Coast tidal wetlands. In D. P. Batzer & Andrew H. Baldwin (Eds.), *Wetland habitats of North America* (pp. 103–116). University of California Press. https://doi.org/10.1525/9780520951419-010

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*(3), 474-486. https://doi.org/10.1046/j.1526-100X.2002.01035.x

Crooks, S., Beers, L., Settelmyer, S., Swails, E., Emmett-Mattox, S., & Cornu, C. (2020). *Scoping assessment for Pacific Northwest blue carbon finance projects*. Silvestrum Climate Associates, TerraCarbon LLC, Strategic Solutions LLC, and the Institute for Applied Ecology. https://www.pnwbluecarbon.org/_files/ugd/43d666_2c5acc56fba34b189903ea528d7ef3be.pdf

Crooks, S., Rybczyk, J., O'Connell, K., Devier, D. L., Poppe, K., & Emmett-Mattox, S. (2014). *Coastal blue carbon opportunity assessment for the Snohomish Estuary: The climate benefits of estuary restoration.* Environmental Science Associates, Western Washington University, EarthCorps, and Restore America's Estuaries. https://estuaries.org/wp-content/uploads/2019/01/snohomish-estuary-executive-summary-feb-2014-final.pdf

Davis, M. J., Woo, I., Ellings, C. S., Hodgson, S., Beauchamp, D. A., Nakai, G., & De La Cruz, S. E. W. (2019). Freshwater tidal forests and estuarine wetlands may confer early life growth advantages for delta-reared Chinook salmon. *Transactions of the American Fisheries Society*, *148*(2), 289–307. https://doi.org/10.1002/tafs.10134

Diefenderfer, H. L. (2007). *Channel morphology and restoration of Sitka spruce* (Picea sitchensis) *tidal forested wetlands, Columbia River, USA.* [Unpublished doctoral dissertation]. University of Washington, College of Forest Resources.

Diefenderfer, H. L., Borde, A. B., & Cullinan, V. I. (2021). Floodplain wetland channel planform, cross-sectional morphology, and sediment characteristics along an estuarine to tidal river gradient. *Journal of Geophysical Research: Earth Surface*, *126*(5), Article e2019JF005391. https://doi.org/10.1029/2019JF005391

Diefenderfer, H. L., Coleman, A. M., Borde, A. B., & Sinks, I. A. (2008). Hydraulic geometry and microtopography of tidal freshwater forested wetlands and implications for restoration, Columbia River, USA. *Ecohydrology & Hydrobiology*, *8*(2–4), 339–361. https://doi.org/10.2478/v10104-009-0027-7

Diefenderfer, H. L., Johnson, G. E., Thom, R. M., Borde, A. B., Woodley, C. M., Weitkamp, L. A., Buenau, K. E., & Kropp, R. K. (2013). *An evidence-based evaluation of the cumulative effects of tidal freshwater and estuarine ecosystem restoration on endangered juvenile salmon in the Columbia River* (PNNL-23037) [Final report prepared for the U.S. Army Corps of Engineers]. Pacific Northwest National Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23037.pdf

Diefenderfer, H. L., Johnson, G. E., Thom, R. M., Buenau, K. E., Weitkamp, L. A., Woodley, C. M., Borde, A. B., & Kropp, R. K. (2016). Evidence-based evaluation of the cumulative effects of ecosystem restoration. *Ecosphere*, *7*(3), Article e01242. https://doi.org/10.1002/ecs2.1242

Diefenderfer, H. L., & Montgomery, D. R. (2009). Pool spacing, channel morphology, and the restoration of tidal forested wetlands of the Columbia River, USA. *Restoration Ecology*, *17*(1), 158–168. https://doi.org/10.1111/j.1526-100X.2008.00449.x

Diefenderfer, H. L., Sinks, I. A., Zimmerman, S. A., Cullinan, V. I., & Borde, A. B. (2018). Designing topographic heterogeneity for tidal wetland restoration. *Ecological Engineering*, *123*, 212–225. https://doi.org/10.1016/j.ecoleng.2018.07.027

Diefenderfer, H. L., Thom, R. M., Johnson, G. E., Skalski, J. R., Vogt, K. A., Ebberts, B. D., Roegner, G. C., & Dawley, E. M. (2011). A levels-of-evidence approach for assessing cumulative ecosystem response to estuary and river restoration programs. *Ecological Restoration*, 29(1-2), pp. 111-132. https://doi.org/10.3368/er.29.1-2.111

Dittbrenner, B. J., Pollock, M. M., Schilling, J. W., Olden, J. D., Lawler, J. J., & Torgersen, C. E. (2018). Modeling intrinsic potential for beaver (*Castor canadensis*) habitat to inform restoration and climate change adaptation. *PLoS ONE*, *13*(2), Article e0192538. https://doi.org/10.1371/journal.pone.0192538

Dittbrenner, B. J., Schilling, J. W., Torgersen, C. E., & Lawler, J. J. (2022). Relocated beaver can increase water storage and decrease stream temperature in headwater streams. *Ecosphere*, *13*(7), Article e4168. https://doi.org/10.1002/ecs2.4168

Drexler, J. Z., Woo, I., Fuller, C. C., & Nakai, G. (2019). Carbon accumulation and vertical accretion in a restored versus historic salt marsh in southern Puget Sound, Washington, United States. *Restoration Ecology, 27*(5), 1117-1127. https://doi.org/10.1111/rec.12941

Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesini, F., Whitfield, A., & Wolanski, E. (2016). Ecoengineering with ecohydrology: Successes and failures in estuarine restoration. *Estuarine, Coastal and Shelf Science*, *176*, 12–35. https://doi.org/10.1016/j.ecss.2016.04.003

Federal Geographic Data Committee. (2012). *Coastal and Marine Ecological Classification Standard* (FGDC-STD-018-2012) [Standard]. https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf

Findlay, S., & Fischer, D. (2013). Ecosystem attributes related to tidal wetland effects on water quality. *Ecology*, *94*(1), 117–125. https://doi.org/10.1890/12-0464.1

Franklin, J. F. and Dyrness, C. T. (1973). *Natural vegetation of Oregon and Washington* (USDA Forest Service Gen. Tech. Rep. PNW-GTR-008). U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Research Station. https://www.fs.usda.gov/research/treesearch/26203

Fuller, R. (2018, April 10). *Climate change and restoration on the Stillaguamish Delta: Lessons learned*. [Conference presentation]. 2018 Ecological Restoration Symposium (https://botanicgardens.uw.edu/wp-content/uploads/sites/7/2018/03/2018-Restoration-Symposium-Agenda.pdf), Seattle, WA, United States. https://botanicgardens.uw.edu/wp-content/uploads/sites/7/2018/04/Fuller_Climate-change-and-restoration-on-the-Stillaguamish-Delta-Lessons-learned.04.10.2018.pdf

Gippel, C. J. (1995). Environmental hydraulics of large woody debris in streams and rivers. *Journal of Environmental Engineering*, *121*(5), 388–395. https://doi.org/10.1061/(ASCE)0733-9372(1995)121:5(388)

Gonor, J. J., Sedell, J. R., & Benner, P. A. (1988). What we know about large trees in estuaries, in the sea, and on coastal beaches. In C. Maser, R. F. Tarrant, J. M. Trappe, & J. F. Franklin (Eds.), *From the forest to the sea: A story of fallen trees* (USDA Forest Service General Technical Report PNW-GTR-229, pp. 83–112). U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Research Station. https://www.fs.usda.gov/research/treesearch/3073

Greene, C., Beamer, E., Chamberlin, J., Hood, G., Davis, M., Larsen, K., Anderson, J., Henderson, R., Hall, J., Pouley, M., Zackey, T., Hodgson, S., Ellings, C., & Woo, I. (2021). *Landscape, density-dependent, and bioenergetic influences upon Chinook salmon in tidal delta habitats: Comparison of four Puget Sound estuaries* (ESRP Report 13-1508). Estuary Salmon and Restoration Program. https://usgs-cru-individual-data.s3.amazonaws.com/melaniedavis/tech_publications/Greene_et_al_2021_chinook_salmon_estuary_density_dependance-1.pdf

Harmon, M. E. & Franklin, J. F. (1989). Tree seedlings on logs in *Picea-Tsuga* forests of Oregon and Washington. *Ecology, 70*(1), pp. 48–59. https://doi.org/10.2307/1938411

Hood, W. G. (2007). Large woody debris influences vegetation zonation in an oligohaline tidal marsh. *Estuaries and Coasts*, *30*(3), 441–450. http://dx.doi.org/10.1007/BF02819390

Hood, W. G. (2012). Beaver in tidal marshes: Dam effects on low-tide channel pools and fish use of estuarine habitat. *Wetlands*, *32*(3), 401–410. https://doi.org/10.1007/s13157-012-0294-8

Janousek, C., Bailey, S., van de Wetering, S., Brophy, L., Bridgham, S., Schultz, M., & Tice-Lewis, M. (2021). *Early post-restoration recovery of tidal wetland structure and function at the Southern Flow Corridor project, Tillamook Bay, Oregon* [Report to the National Oceanic and Atmospheric Administration and Tillamook County, Oregon]. https://ir.library.oregonstate.edu/concern/technical_reports/tx31qr89q

Janousek, C. N., Buffington, K. J., Thorne, K. M., Guntenspergen, G. R., Takekawa, J. Y., & Dugger, B. D. (2016). Potential effects of sea-level rise on plant productivity: Species-specific responses in northeast Pacific tidal marshes. *Marine Ecology Progress Series*, *548*, 111–125. https://doi.org/10.3354/meps11683

Johnson, L. K., & Simenstad, C. A. (2015). Variation in the flora and fauna of tidal freshwater forest ecosystems along the Columbia River estuary gradient: Controlling factors in the context of river flow regulation. *Estuaries and Coasts*, *38*(2), 679–698. https://doi.org/10.1007/s12237-014-9839-9

Jones, C. G., Lawton, J. H., & Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos*, *69*(3), 373–386. https://doi.org/10.2307/3545850

Jones, K. K., Cornwell, T. J., Bottom, D. L., Campbell, L. A., & Stein, S. (2014). The contribution of estuary-resident life histories to the return of adult *Oncorhynchus kisutch*. *Journal of Fish Biology*, *85*(1), 52–80. https://doi.org/10.1111/jfb.12380

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*(10), 5679–5692. https://doi.org/10.1111/gcb.15248

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*(2), 158–181. https://doi.org/10.1111/j.1467-2979.2011.00421.x

Lavergne, S., & Molofsky, J. (2004). Reed canary grass (*Phalaris arundinacea*) as a biological model in the study of plant invasions. *Critical Reviews in Plant Sciences, 23*(5), 415–429. https://doi.org/10.1080/07352680490505934

Marcoe, K., & Pilson, S. (2017). Habitat change in the lower Columbia River estuary, 1870–2009. *Journal of Coastal Conservation*, *21*, 505–525. https://link.springer.com/article/10.1007/s11852-017-0523-7

Marten, S. (2022). *Beaver herbivory behavior and its impact on habitat restoration at the South Slough National Estuarine Research Reserve* [Paper presentation]. Master of Natural Resources Capstone Defense Presentation, Oregon State University, Corvallis, OR, United States. https://ir.library.oregonstate.edu/concern/defaults/wd376419k

McGee, G. G., & Birmingham, J. P. (1997). Decaying logs as germination sites in northern hardwood forests. *Northern Journal of Applied Forestry*, *14*(4), 178–182. https://doi.org/10.1093/njaf/14.4.178

Naiman, R. J., Balian, E. V, Bartz, K. K., Bilby, R. E., & Latterell, J. J. (2002). Dead wood dynamics in stream ecosystems. In W. F. Laudenslayer Jr., P. J. Shea, B. E. Valentine, C. P. Weatherspoon, & T. E. Lisle (Eds.), *Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests* [November 2-4, 1999. Reno, Nevada] (General Technical Report PSW-GTR-181, pp. 23–48). U.S. Department of Agriculture, U.S. Forest Service. https://doi.org/10.2737/PSW-GTR-181

Peterson, C. H., Able, K. W., DeJong, C. F., Piehler, M. F., Simenstad, C. A., & Zedler, J. B. (2008). Practical proxies for tidal marsh ecosystem services: Application to injury and restoration. In D. W. Sims (Ed.), *Advances in marine biology* (Vol. 54, pp. 221–266). https://www.sciencedirect.com/bookseries/advances-in-marine-biology/vol/54/suppl/C

Petro, V. M., Taylor, J. D., & Sanchez, D. M. (2015). Evaluating landowner-based beaver relocation as a tool to restore salmon habitat. *Global Ecology and Conservation*, *3*, 477–486. https://doi.org/10.1016/j.gecco.2015.01.001

Pollock, M. M., Lewallen, G. M., Woodruff, K., Jordan, C. E., & Castro, J. M. (Eds.). (2023). *The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains* (Version 2.02). U.S. Fish and Wildlife Service. https://www.fws.gov/media/beaver-restoration-guidebook

Pollock, M. M., Pess, G. R., Beechie, T. J. & Montgomery, D. R. (2004). The importance of beaver ponds to coho salmon production in the Stillaguamish River basin, Washington, USA. *North American Journal of Fisheries Management 24*:749–760. https://duff.ess.washington.edu/grg/publications/pdfs/Pollock.pdf

Poppe, K. L., & Rybczyk, J. M. (2021). Tidal marsh restoration enhances sediment accretion and carbon accumulation in the Stillaguamish River estuary, Washington. *PLoS ONE*, *16*(9), Article e0257244. https://doi.org/10.1371/journal.pone.0257244

Rice, C. A., Hood, W. G., Tear, L. M., Simenstad, C. A., Williams, G. D., Johnson, L. L., Feist, B. E., & Roni, P. (2005). Monitoring rehabilitation in temperate North American estuaries. In P. Roni (Ed.), *Monitoring stream and watershed restoration*. American Fisheries Society. https://doi.org/10.47886/9781888569636

Roegner, G. C., Diefenderfer, H. L., Borde, A. B., Thom, R. M., Dawley, E. M., Whiting, A. H., Zimmerman, S. A., & Johnson, G. E. (2008). *Protocols for monitoring habitat restoration projects in the lower Columbia River and estuary* [Final report prepared for the U.S. Army Corps of Engineers]. Pacific Northwest National Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-15793.pdf

Simenstad, C., Wick, A., van de Wetering, S., and Bottom, D. (2003). Dynamics and ecological functions of wood in estuarine and coastal marine ecosystems. In S. V. Gregory, K. L. Boyer, and A. M. Gurnell (Eds.), *The ecology and management of wood in world rivers* (pp. 265-277). American Fisheries Society. https://doi.org/10.47886/9781888569568

Sinks, I. A., Borde, A. B., Diefenderfer, H. L., & Karnezis, J. P. (2021). Assessment of methods to control invasive reed canarygrass (*Phalaris arundinacea*) in tidal freshwater wetlands. *Natural Areas Journal*, *41*(3), 172–182. https://doi.org/10.3375/043.041.0303

Smart, L. S., Taillie, P. J., Poulter, B., Vukomanovic, J., Singh, K. K., Swenson, J. J., Mitasova, H., Smith, J. W., & Meentemeyer, R. K. (2020). Aboveground carbon loss associated with the spread of ghost forests as sea levels rise. *Environmental Research Letters*, *15*(10), Article 104028. https://doi.org/10.1088/1748-9326/aba136

Swanson, K. M., Drexler, J. Z., Schoellhamer, D. H., Thorne, K. M., Casazza, M. L., Overton, C. T., Callaway, J. C., & Takekawa, J. Y. (2014). Wetland accretion rate model of ecosystem resilience (WARMER) and its application to habitat sustainability for endangered species in the San Francisco estuary. *Estuaries and Coasts*, *37*(2), 476–492. https://doi.org/10.1007/s12237-013-9694-0

Stewart-Oaten, A., Murdoch, W. W., & Parker, K. R. (1986). Environmental impact assessment: “Pseudoreplication” in time? *Ecology*, *67*(4) 929–940. https://doi.org/10.2307/1939815

Sweet, W. V., Hamlington, B. D., Kopp, R. E., Weaver, C. P., Barnard, P. L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A. S., Krasting, J. P., Larour E., Marcy, D., Marra, J. J., Obeysekera, J., Osler, M., Pendleton, M., ... Zuzak, C. (2022). *Global and regional sea level rise scenarios for the United States: Updated mean projections and extreme water level probabilities along U.S. coastlines* (NOAA Technical Report NOS 01). U.S. National Oceanic and Atmospheric Administration, National Ocean Service. https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M. J., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature,* 504(7478), 79–83. https://doi.org/10.1038/nature12859

Thayer, G. W., McTigue, T. A., Salz, R. J., Merkey, D. H., Burrows, F. M., & Gayaldo, P. F. (Eds.). (2005). Science-based restoration monitoring of coastal habitats: Volume Two: Tools for monitoring coastal habitats (NOAA Coastal Ocean Program Decision Analysis Series No. 23). U.S. National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Center for Sponsored Coastal Ocean Research. https://coastalscience.noaa.gov/data_reports/science-based-restoration-monitoring-of-coastal-habitats-volume-two-tools-for-monitoring-coastal-habitats/

Thomas, D. W. (1983). *Changes in Columbia River estuary habitat types over the past century*. Columbia River Estuary Study Taskforce, Columbia River Estuary Data Development Program. https://www.estuarypartnership.org/sites/default/files/resource_files/7%20-%20CHANGES%20IN%20COLUMBIA%20RIVER%20ESTUARY%20HABITAT%20TYPES%20OVER%20THE%20PAST%20CENTURY.pdf

Troost, S., Beers, L., Clayton, A., Cornu, C., Crooks, S., Ruther, E., Theuerkauf, K., & Wade, H. (2021). *Incorporating coastal blue carbon data and approaches in Oregon's first generation natural and working lands proposal* [White paper submitted to the Oregon Global Warming Commission, July 2021 (Updated September 2021)].

Wasson, K., Tanner, K. E., Woofolk, A., McCain, S., & Suraci, J. P. (2021). Top-down and sideways: Herbivory and cross-ecosystem connectivity shape restoration success at the salt marsh-upland ecotone. *PLoS ONE*, *16*(2), Article e0247374. https://doi.org/10.1371/journal.pone.0247374

Weber, N., Bouwes, N., Pollock, M. M., Volk, C., Wheaton, J. M., Wathen, G., Wirtz, J., & Jordan, C. E. (2017). Alteration of stream temperature by natural and artificial beaver dams. *PLoS ONE*, *12*(5), Article e0176313. https://doi.org/10.1371/journal.pone.0176313

Williams, T., Janousek, C. N., McKeon, M. A., Diefenderfer, H. L., Cornu, C. E., Borde, A. B., Apple, J., Brophy, L., Norwood, M., Schultz, M., & Bridgham, S. (2024). *A regional assessment of methane and nitrous oxide emissions from reference, restored, and disturbed tidal wetlands in the Pacific Northwest, USA* [Manuscript submitted for publication]. Oregon State University.

Wohl, E. (2021). Legacy effects of loss of beavers in the continental United States. *Environmental Research Letters*, *16*(2), Article 025010. https://doi.org/10.1088/1748-9326/abd34e

Woo, I., Davis, M., Ellings, C., Hodgson, S., Takekawa, J., Nakai, G., & DeLaCruz, S. (2019). A mosaic of estuarine habitat types with prey resources from multiple environmental strata supports a diversified foraging portfolio for juvenile Chinook salmon. *Estuaries and Coasts*, *42*, 1938–1954. https://doi.org/10.1007/s12237-019-00613-2

FURTHER READING – GUIDANCE ON METHODOLOGY

Some of these publications appear in the reference section, but they are emphasized here for ease of access.

Brophy, L. S. (2009). Effectiveness Monitoring at Tidal Wetland Restoration and Reference Sites in the Siuslaw River Estuary: A Tidal Swamp Focus [Final report to Ecotrust, Portland, Oregon]. Green Point Consulting.

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 Tidal Wetlands of Oregon, USA [Amended final report prepared for the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)]. Institute for Applied Ecology, Estuary Technical Group. Reference conditions database: http://oregonexplorer.info/wetlands/DataCollections/ReferenceSiteData

Diefenderfer, H. L., Borde, A. B., & Cullinan, V. I. (2021). Floodplain Wetland Channel Planform, Cross-Sectional Morphology, and Sediment Characteristics Along an Estuarine to Tidal River Gradient. *Journal of Geophysical Research: Earth Surface*, *126*(5), Article e2019JF005391. Provides models and classifications to inform channel-network restoration design.

Diefenderfer, H. L., Sinks, I. A., Zimmerman, S. A., Cullinan, V. I., & Borde, A. B. (2018). Designing Topographic Heterogeneity for Tidal Wetland Restoration. *Ecological Engineering*, *123*, 212–225. Provides a full review regarding the design of mounds.

Fuller, R. (2018, April 10). Climate Change and Restoration on the Stillaguamish Delta: Lessons Learned. Presentation to the Society for Ecological Restoration.

Goldfarb, B. (2019, January 29). The Gnawing Question of Saltwater Beavers. *Hakai Magazine*.

Pollock, M. M., Lewallen, G. M., Woodruff, K., Jordan, C. E., & Castro, J. M. (Eds.). (2023). The Beaver Restoration Guidebook: Working With Beaver to Restore Streams, Wetlands, and Floodplains (Version 2.02). U.S. Fish and Wildlife Service. A very recent and thorough guidebook on beavers and habitat restoration.

Roegner, G. C., Diefenderfer, H. L., Borde, A. B., Thom, R. M., Dawley, E. M., Whiting, A. H., Zimmerman, S. A., & Johnson, G. E. (2008). Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary [Final report prepared for the U.S. Army Corps of Engineers].

Sinks, I. A., Borde, A. B., Diefenderfer, H. L., & Karnezis, J. P. (2021). Assessment of Methods to Control Invasive Reed Canarygrass (*Phalaris arundinacea*) in Tidal Freshwater Wetlands. *Natural Areas Journal*, *41*(3), 172–182. Provides a full review of various ecological and active control methods used to manage reed canarygrass at restoration sites in the Pacific Northwest.

Thayer, G. W., McTigue, T. A., Salz, R. J., Merkey, D. H., Burrows, F. M., & Gayaldo, P. F. (Eds.). (2005). Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats (NOAA Coastal Ocean Program Decision Analysis Series No. 23). U.S. National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Center for Sponsored Coastal Ocean Research.

APPENDIX: TIDAL SWAMP PRACTITIONER SURVEY QUESTIONS

Tidal Swamp Restoration Projects: Techniques and Results

PMEP

PACIFIC MARINE & ESTUARINE FISH HABITAT PARTNERSHIP

PMEP is a nationally recognized partnership that seeks to advance regional and national goals relating to fish habitat. With its partners, PMEP synthesizes the best available information to help protect and restore West Coast fish habitat, including compiling datasets that enhance our understanding of this habitat. PMEP also provides, with partners, targeted restoration and conservation funding to support on-the-ground work.

Purpose & Objective

The objective of this survey is to improve our understanding of tidal swamp restoration projects along the U.S. West Coast, including techniques used and success stories / lessons learned.

SURVEY QUESTIONS

Respondent Information

Respondent Name, Organization Name, Email Address, Phone Number

Do your projects include restoration of tidal swamp habitats?

Please share the name(s) of project design team members and or company/consultants used.

Project Manager (for tidal swamp work) – name and contact information for the person leading the tidal swamp restoration efforts.

Project Information

Total acres of estuary restoration project:

Acres of tidal swamp included in restored area:

Month and year of project completion:

Please upload a project report and maps if available (up to 10 MB).

Please upload spatial data specific to the tidal swamp site if available.

Please share representative tidal swamp site photos if available.

Reference Site

Please describe any nearby tidal swamp reference sites used to guide restoration design.

Please identify estuary by name and include any useful landmarks. Coordinate locations are also welcome if available—preferably latitude/longitude in decimal degrees.

Dominant plants at reference site:

Are beaver present at reference site?

- Yes
- No
- Unknown

Are large wood and pools present at reference site?

- Yes
- No
- Unknown

Please share additional reference sources that helped to guide your effort:

- Provide name, organization, and contact information of people you spoke with or learned from to guide your tidal swamp restoration work.
- Provide additional location information for project sites you may have visited or learned from in planning your project.

Techniques & Monitoring

What was the design elevation for the restored tidal swamp? (Geodetic elevation (NAVD88)—please specify units.)

What was the design elevation relative to MHHW, MLLW, or other tidal datum? (Please specify relative datum and units.)

What tidal swamp-specific restoration techniques were used? (Check those that apply.)

- Soil mounds
- Soil-filled cribs
- Nurse logs
- Large wood placed in channels or on floodplain
- Other _______________

Species Planted

Please identify species planted. (Please check all that apply.)

- __ Sitka spruce
- __ Western red cedar
- __ Black cottonwood
- __ Red alder
- __ Black twinberry
- __ Oregon (Pacific) crabapple
- __ Red osier dogwood
- __ Douglas spirea (hardhack)
- __ Cascara
- __ Salmonberry
- __ Oregon ash
- __ Buttonbush
- __ Pacific Wax Myrtle
- __ Sweetgale (bog myrtle)
- __ Bitter (Oregon) cherry
- __ Western skunk cabbage
- __ Slough sedge
- __ Willow: Hooker’s, coast, or dune
- __ Willow: Shining or Pacific
- __ Willow: Sitka
- __ Willow: Scouler’s
- __ Other ____________

Monitoring

What is monitored in the tidal swamp portion of the restoration area? (Please check all that apply.)

- __ As-built elevation survey
- __ Survival of plantings
- __ Vegetation cover/frequency
- __ Reed canarygrass cover/frequency
- __ Inundation frequency (tide gauge)
- __ In-channel salinity
- __ In-channel water temperature
- __ Shallow groundwater level
- __ Water or soil salinity/conductivity
- __ Sediment accretion/erosion
- __ Soil organic matter
- __ Soil texture
- __ Soil pH
- __ Soil bulk density
- __ Channel depth
- __ Channel width
- __ Pool spacing
- __ Beaver presence
- __ Fish use

— Macroinvertebrates
— Other ______________

Existing Conditions

What are the dominant species of woody and nonwoody vegetation on the site currently (prior to restoration)?

Are invasive species prevalent at the restoration site (and if so, what species)?

Final Thoughts

Thank you for your time. Please provide any final thoughts or ideas you would like to share regarding tidal swamp restoration: