

Effectiveness Monitoring at Tidal Wetland Restoration and Reference Sites in the Siuslaw River Estuary: *A Tidal Swamp Focus*



North Fork Siuslaw River Tidal Swamp Restoration (site S65), 1 month after dike breaching and meander construction (9/10/07). Photo courtesy of Oregon Department of Transportation Photo and Video Services.

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Table of contents

Executive summary 5

Focus of study 7

Study sites 8

 Summary of site characteristics 8

 Wetland class 8

Restoration sites 9

 Site S59 9

 Site S65 10

Reference sites 11

 Selection of reference sites for restoration site S59 11

 Selection of reference sites for restoration site S65 12

 Site S11 (Cox Island) 12

 Site S63 13

 Site Y28 13

Monitoring program summary 13

Methods: Summary 15

Methods: Details not covered in QAPP 17

 Sampling design 17

 Elevation survey methods 18

 Elevation datums 19

 Tidal inundation regime, tidal datums, and the “river flow effect” 20

 North Fork Siuslaw River sites (S59, S63, and S65) 20

 Yaquina tidal swamp (Site Y28) 21

 Site S11 (Cox Island) 21

 Tidal inundation regime metrics 22

 Groundwater fluctuation 22

 Surface water salinity 23

 Vegetation 23

 Mapping of major vegetation types 23

 Plant community composition 23

 Landscape setting 25

 Habitat class interspersions 25

 Slope 25

 Aspect 25

 Geomorphic setting 25

Results 26

 Elevation 26

 Hydrology 27

 Tidal inundation regime and the “river flow effect” 27

 Tidal datums 28

 Groundwater fluctuation 28

 Surface water salinity 31

 Soils 32

 Vegetation 33

 Vegetation mapping 33

Plant community composition	33
Woody species stem density and basal area	41
Landscape setting.....	41
Discussion.....	42
Elevation and subsidence.....	42
Tidal vs. geodetic datums	43
Hydrology	43
Tidal inundation regime.....	43
Water table depth	44
Surface water salinity.....	45
Soils.....	46
Vegetation.....	47
Vegetation mapping.....	47
Plant community composition: Restoration-reference site comparisons.....	48
Restoration site S59	48
Restoration site S65	48
Woody species density and basal area.....	49
Tidal swamp plant communities	49
Post-restoration trends in plant community composition at site S65.....	49
Landscape setting.....	50
Habitat class interspersion	50
Slope and aspect.....	51
Geomorphic setting.....	51
Conclusions.....	51
Controlling factors in tidal swamp development.....	51
Beaver and Sitka spruce as “system engineers?”	52
Significance of tidal swamp data	53
Site S59: General conditions and wetland functions	54
Site S65: Early restoration trajectory and wetland functions.....	55
Recommendations for future monitoring.....	56
Collaborative and related projects	58
Products from this study	60
List of tables, figures, and maps	61
Literature cited.....	64
Appendix 1. Maps.....	69
Appendix 2. Additional figures.....	81
Appendix 3. Photodocumentation at S65 Tidal Swamp Restoration.....	94
Appendix 4. General site photos.....	96
Appendix 5. Quality Assurance Project Plan.....	105

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Executive summary

This project was part of the Siuslaw Watershed Restoration Initiative, a project funded by the U.S. Environmental Protection Agency's Targeted Watersheds Program. We designed and established a monitoring program at five sites totaling 319 A: two tidal wetland restoration sites (97 A) and two reference sites (205 A) in the Siuslaw River estuary, and one 17 A reference site in the Yaquina River estuary. Both restoration sites were historically Sitka spruce tidal swamp, but one has subsided and is currently restoring to tidal marsh. The three reference sites – two least-disturbed tidal swamps and one least-disturbed tidal marsh – were selected to represent the full range of historic and current conditions at the restoration sites.

Goals for this project were:

- Thoroughly document site conditions during a single year (2006)
- Provide urgently-needed data on biology and physical characteristics of forested and scrub-shrub tidal wetlands (“tidal swamps”)
- Compare restoration sites to reference sites
- Establish a baseline to enable detection of future change
- Provide data to guide tidal wetland restoration design, evaluate restoration effectiveness, and guide adaptive management in the Siuslaw and other estuaries
- Develop collaborative research and monitoring partnerships to leverage results
- Disseminate results to the practitioner community to help guide future restoration efforts

Throughout this report, the terms “tidal marsh” and “tidal swamp” are used to refer to two distinctively different types of estuarine wetlands:

Tidal marsh refers to a tidal wetland dominated by emergent vegetation (mainly grasses, sedges, and rushes)

Tidal swamp refers to a tidal wetland dominated by woody vegetation (shrubs and/or trees).

The majority of field work was conducted during 2006; funding from this and related projects allowed us to continue monitoring some parameters in 2007-2008. Monitoring parameters were selected using a conceptual model of site function. We measured indicators in three groups: controlling factors (“ecological drivers”), ecosystem structure, and ecosystem function (biological characteristics). Monitored metrics included tidal hydrology, groundwater hydrology, elevation, surface water salinity, soil characteristics (texture, salinity, pH, and organic matter content), plant community composition, woody species density and basal area, habitat class interspersion, slope, aspect, and geomorphic setting. Monitoring focused on permanent plots to facilitate future monitoring and analysis of restoration trajectory.

Results show that the restoration sites have levels of controlling factors and structural characteristics that are appropriate for the development of desired wetland functions. The data from the reference sites provide new insight into tidal swamp ecology. These reference data are urgently needed to help guide tidal swamp restoration, since nearly all of Oregon's tidal swamps have been lost to coastal development and agriculture, and losses still continue today.

Notable findings include:

1. Natural processes and controlling factors have been successfully re-established at both restoration sites, and tidal wetland restoration is well underway, with no apparent obstacles to success.
2. Field observations and assessments show that both restoration sites are performing valued wetland functions.

3. Dike breaching during 2007 at the tidal swamp restoration site greatly increased tidal inundation events, from 6 days/yr before restoration to 119 days/yr after restoration. (The restoration work was implemented through a related project.)
4. Tidal swamp reference sites in this study had strongly brackish surface water and soil porewater salinities; sites included willow and Sitka spruce swamps. Brackish salinities were observed in winter as well as summer.
5. This study represents the first comprehensive data on the controlling factors, site structure, and biology of least-disturbed brackish tidal swamps of Oregon's outer coast.
6. Tidal swamps dominated by Sitka spruce and black twinberry had the highest summer salinities (5-20ppt, in the mesohaline range). The tidal swamp with oligohaline summer salinity (<5ppt) was dominated by Hooker willow, slough sedge and skunk cabbage.
7. Vegetation data from the brackish swamps were used to add new descriptions of brackish tidal swamps (estuarine intertidal scrub-shrub and estuarine intertidal forested wetlands) for inclusion in Oregon's plant community classification system.
8. Brackish tidal swamps had wetland surface elevations slightly above mean higher high water (0.5 to 0.7 ft above MHHW). Elevations of high marsh at the Cox Island reference site were similar (about 0.4 ft above MHHW).
9. Tidal swamp wetland surfaces were regularly inundated by the highest tides each month even in summer; inundation was much more frequent in winter.
10. River flows had a strong influence on inundation regimes in the tidal swamps. Models show that high river flows can triple inundation frequency during winter or spring.
11. Groundwater fluctuation is probably a controlling factor in tidal swamp ecology. Water tables at tidal swamp reference sites were highly responsive to tidal cycles, rising and falling with the tides even during neap tide cycles when the wetland surface was not inundated.
12. Major soil subsidence (2-3ft) has occurred at one of the diked former tidal swamp sites (site S59). The site is now in the process of restoration to tidal marsh instead of tidal swamp.
13. Based on historic vegetation mapping from the Oregon Natural Heritage Program, a substantial part of Cox Island was a Sitka spruce swamp in the 1850's. Elevations in this area are still suitable for re-establishment of spruce swamp; soil salinity should be further investigated.

Our results were immediately applied in developing a design for tidal swamp restoration at one of the study sites. Restoration was implemented at this site under a separate project in 2007. We conducted post-restoration follow-up monitoring at that site in 2008 under a related project. Monitoring will continue for 15 years, a duration suitable for slow-developing tidal swamp restoration sites.

We collaborated with numerous federal, state and local agencies and organizations to deploy monitoring equipment, model inundation regimes, survey site elevations, and interpret data. We are disseminating the results from this study to tidal wetland restoration practitioners throughout Oregon to help guide future restoration efforts.

Focus of study

This study focused on two tidal wetland types that are generally viewed as a high priority for restoration in Oregon: tidal swamp and tidal marsh. Oregon's tidal wetlands have been classified in many ways, but the most obvious distinction to the casual observer is vegetation. In terms of vegetation, two main types of tidal wetlands exist in Oregon. The first is tidal marsh, which has grassy or other low-growing non-woody vegetation and is classified as emergent wetland in the Cowardin classification system (Cowardin 1986). (Tidal marsh is further divided into high marsh and low marsh in most other classification systems.)

The second major tidal wetland type -- and a major focus of this study -- is tidal swamp. Tidal swamp is dominated by woody vegetation (trees or shrubs) and is classified as "forested" or "scrub-shrub" wetland in the Cowardin system. Under undisturbed conditions in Oregon, tidal marsh predominates in the marine and brackish zones of the estuary, and tidal swamp predominates further up the estuary in the lower brackish (mesohaline to oligohaline) and freshwater tidal zones of the estuary. Tidal swamp can also be on the margins of the marine salinity zone where freshwater dilutes ocean water, such as along tributary streams, on high natural levees, and in hillslope seepage zones.

Tidal swamp was once a major component of the Oregon coastal landscape, but this wetland type has been almost completely lost due to diking, tree removal, ditching, fill placement, and other alterations (Brophy 2007a). Loss of tidal swamps in the Siuslaw River estuary has been particularly high. A high proportion of tidal wetlands in the Siuslaw River estuary were once tidal swamp (Map 3, Appendix 1, Map 3), but 97% of these former tidal swamps have been lost completely or converted to other types of wetlands (Brophy 2005a). Because of these losses, tidal swamp restoration is a high priority in Oregon and in the Siuslaw in particular.

Ecological data on tidal swamps are urgently needed to help guide site selection, design, and evaluation of tidal swamp restoration projects. Data on tidal swamps in Oregon are almost completely lacking from the literature, perhaps because so few remnants of these wetlands remain and awareness of this habitat class has been very low. Recently, several authors have documented characteristics of freshwater tidal swamps in the Columbia River Estuary (Diefenderfer and Montgomery 2008; Elliot 2008) but data are not available for Oregon's other estuaries or for brackish tidal swamps. Therefore, we made a strong effort during this project to locate and obtain access to tidal swamp reference sites, and to help focus restoration efforts on potential tidal swamp sites in the Siuslaw River estuary. We felt these activities could considerably advance the state of knowledge of tidal swamp ecology in Oregon. As a result of this effort, we were able to monitor two tidal swamp reference sites during this project, one on the North Fork Siuslaw River and one on the Yaquina River. We also monitored one reference site that originally contained a range of habitats from low marsh to tidal swamp, but which is now tidal marsh due to tree removal (Cox Island, a Nature Conservancy preserve). Details are provided in "Study sites" below.

Study sites

Site numbers used in this report were established in the Siuslaw Tidal Wetland Prioritization (Brophy 2005a) and the Yaquina-Alesea Basins Estuarine Wetland Site Prioritization (Brophy 1999).

We monitored two tidal wetland restoration sites and two reference sites in the Siuslaw River estuary (Appendix 1, Map 1; Appendix 4, Photos A14-A16), and one additional reference site in the Yaquina River estuary (Appendix 1, Map 2; Appendix 4, Photo A7). One of the restoration sites (S59) had already been restored 5 years prior to this study; the other (S65) was restored during the study period. Site characteristics are summarized in Table 1 and described in detail below.

Summary of site characteristics

Table 1 shows the general characteristics of the study sites, including restoration or reference status, wetland class, alterations, and channel conditions.

Wetland class

Historic wetland classes shown in Table 1 refer to conditions immediately prior to European settlement of the area, and are based on knowledge of estuary biology and geomorphology as well as historic vegetation mapping (Hawes *et al.* 2002; Appendix 1 Map 3). Current wetland classes shown in Table 1 are based on field measurements at the study sites, including surface water salinity and vegetation. Classes shown may therefore differ from the National Wetland Inventory, which is based on remote data. HGM classes are those defined in Adamus (2006); Cowardin classes are those defined in Cowardin *et al.* 1979.

Table 1. Study site characteristics

Estuary	Siuslaw				Yaquina
	S11 (Cox Island)	S59	S63	S65	Y28
Size (acres)	197.2	84.8	7.4	12.1	17
Tidal water body	Siuslaw River	North Fork Siuslaw River	North Fork Siuslaw River	North Fork Siuslaw River	Yaquina River
River mile	7	3	4	5	16.5
Salinity zone	marine	mixing (brackish)	mixing (brackish)	freshwater tidal	mixing (brackish)
Restoration vs. reference	reference	restoration	reference	restoration	reference
Year restored	n/a	2001	n/a	2007	n/a
Historic wetland type (1850s)*	tidal marsh and Sitka spruce tidal swamp	Sitka spruce tidal swamp	Sitka spruce and shrub tidal swamp	Sitka spruce tidal swamp	Sitka spruce and shrub tidal swamp
Historic Cowardin class	estuarine emergent and estuarine forested	estuarine forested	estuarine scrub-shrub and forested	palustrine forested (tidally-influenced)	estuarine scrub-shrub and forested
Current Cowardin class	estuarine emergent	estuarine emergent	estuarine scrub-shrub and forested	palustrine emergent	estuarine emergent, scrub-shrub and forested
HGM class (current and historic)	marine-sourced low and high tidal fringe	river-sourced tidal fringe	river-sourced tidal fringe	river-sourced tidal fringe	river-sourced tidal fringe
Alterations, impacts	tree removal, likely grazing	diking and grazing; minor ditching. Dike was breached in 1996-2001.	diking; naturally breached	diking and grazing. Dike was breached in 2007.	possible selective tree removal
Channel condition	natural, meandering	mostly natural, meandering; some ditching	natural, meandering	ditched; 1 meander restored in 2007	natural, meandering

*from Hawes *et al.* (2002)

Restoration sites

Site S59

Site S59 (Maps 5 and 10) was among the highest-ranked sites in the Tidal Wetland Prioritization for the Siuslaw River Estuary (Brophy 2005a). The site was historically tidal swamp, but it has undergone 2-3 ft of subsidence. As a result, the site is currently in the process of restoration to tidal marsh. About half of the site was tidal marsh in 2004 (Appendix 1, Map 10); the other half was mud flat (mapped as “water” in Scranton 2004). Pre-settlement vegetation was mapped by Hawes *et al.* (2002) as “swamp, composition unknown” on most of the site and “Sitka spruce swamp” on the north portion (Appendix 1, Map 3). The site was diked for use as pasture prior to 1939. During a river flood event (probably in 1996), the site’s tide gate failed and the dike breached. A perpetual conservation easement was established on the site in 2000; two smaller dike breaches were opened as part of the easement process in February 2001 (Kate Danks, NRCS District Conservationist, personal communication).

Subsidence is caused by oxidation of soil organic matter, compaction by livestock and farm machinery, and other factors (Frenkel and Morlan 1991); it is a common phenomenon at diked tidal wetlands. Over time, if sufficient sediment accretion or organic matter accumulation occurs, tidal swamp may eventually re-establish on the site, but the time required is likely to be substantial. One study showed that re-establishment of high marsh through sediment accretion at a subsided site in Oregon could take 50 years or more (Frenkel and Morlan 1991); another study investigated the potential to speed this process through manipulation of surface elevations (Cornu and Sadro 2002). Compared to tidal marsh, tidal swamp is likely to take even longer to re-establish due to slower-growing woody vegetation and higher pre-disturbance elevations. In the freshwater tidal zone of the Columbia River estuary, Diefenderfer *et al.* (2008) measured post-restoration accretion rates of 2.4cm/yr in a diked former tidal swamp with subsidence of about 70cm (2.3ft), and estimated recovery times of 20-54 yrs or more.

Site S65

Site S65 (Maps 7, 9 and 11) is a tidal swamp restoration site that was ranked among the 10 highest-priority restoration sites in the Siuslaw River estuary (Brophy 2005a). This site, like site S59, was diked for use as pasture prior to 1939. Its historic vegetation prior to diking cannot be determined from the Oregon Natural Heritage Program's historic vegetation map due to scale issues (the site is not distinguished from surrounding upland forest). The site's vegetation in 2005 (before restoration) consisted of about 7A of nontidal forested wetland and about 5A of diked reed canarygrass pasture (palustrine emergent wetland) (Map 11). The site's dike was low – only about 2 feet high – but it served the desired purpose because it was located atop a substantial natural levee. Prior to restoration, three culverts, each about 1 ft in diameter, provided drainage off the site. The culverts may have originally had tide gates, but no tide gates were present during this study. Prior to restoration, the site inundated only during very high river flow events; tidal exchange was greatly reduced by the dike and restrictive culverts.

Like many restoration sites, site S65 contained a mix of higher and lower-functioning wetlands. Monitoring at this site focused on the most heavily altered area: the old pasture (4.2A) on the west side of the site, which was dominated by reed canarygrass in 2005. In 2007, the 4.2A old pasture was selected as a mitigation site for wetland impacts at the North Fork Siuslaw River Bridge (see “Collaborative and related projects” below). Restoration design, implementation and follow-up monitoring were funded by the Oregon Department of Transportation (ODOT); detailed information is provided in the Offsite Mitigation Plan (Brophy 2007b) and in the Year 1 effectiveness monitoring report (Brophy 2008).

During restoration in 2007, tidal hydrology was restored by breaching the dike, filling ditches, removing restrictive culverts, and excavating a meandering pilot tidal channel (Appendix 3; Appendix 4, Photos A1-A5). In addition, the site was extensively planted with typical tidal swamp shrubs and trees, including Sitka spruce, black twinberry, Pacific crabapple, and Hooker willow (Appendix 4, Photo A6).

The current study provided baseline data from the restoration site and two reference sites (described below); these data were essential for determining the feasibility of restoration at site

S65. The reference site baseline data also guided restoration design at the site, and are being used to evaluate restoration effectiveness. ODOT is funding post-restoration follow-up monitoring at the site for 15 years, creating an outstanding opportunity to learn about the trajectory of tidal swamp restoration in Oregon's outer coast estuaries. Year 1 effectiveness monitoring was conducted in 2008 and is described briefly in this report; for details, see Brophy (2008).

Reference sites

In this report, we use the term "reference sites" to refer to least-disturbed sites illustrating desired target conditions or pre-disturbance conditions.

Science-based restoration monitoring requires careful selection of appropriate reference sites or reference datasets (Roegner *et al.* 2008, Rice *et al.* 2005, Merkey 2006). At many tidal wetland restoration sites in Oregon, controlling factors and structural conditions are distinctly different from the sites' historic conditions, due to subsidence of the soil surface (Cornu and Sadro 2002, Frenkel and Morlan 1991). To allow accurate evaluation of restoration effectiveness at these sites, a suite of reference sites may be more appropriate than a single reference site. Reference sites at elevations similar to the restoration site's subsided condition can provide insight into recovery of wetland functions in the early years. As a site recovers elevation (through sediment accretion or organic matter accumulation), comparisons can be made to reference sites at higher elevations similar to the restoration site's pre-disturbance condition. Such a sequence of comparisons – a form of "trajectory analysis" – could help evaluate the site's potential to recover pre-disturbance wetland functions.

We used our experience in Oregon's midcoast estuaries to select reference sites appropriate to the project's restoration sites. Finding least-disturbed tidal swamp reference sites was a major challenge, since 97% of tidal swamps have been lost from the Siuslaw River estuary (Brophy 2005a). To gather adequate reference data, we included a tidal swamp reference site in the Yaquina estuary (Site Y28).

Selection of reference sites for restoration site S59

Because site S59 was significantly subsided, we selected three different reference sites to provide a range of data comparable to subsided and historic conditions:

- 1) Least-disturbed tidal marsh with native vegetation in the mesohaline zone, including both low and high marsh, for comparison to current subsided conditions (site S11);
- 2) Least-disturbed tidal swamp with native vegetation in the mesohaline zone, for comparison to pre-subsidence conditions (sites S63 and Y28).

Site S11 had a broad surface that matched the general shape of site S59, but its landscape setting differed (S11 is an island, whereas site S59 is a channel fringe wetland). All the reference sites were undiked and unditched wetlands with little freshwater inflow, which matched physical characteristics of site S59.

Selection of reference sites for restoration site S65

Selecting reference sites was easier for site S65 because it did not appear to have subsided from its original tidal swamp elevation. We selected sites S63 and Y28 as the appropriate least-disturbed reference sites. These two sites had native vegetation and physical characteristics matching the physical setting at site S65:

- 1) Tidal swamp located in the slightly brackish (low mesohaline or oligohaline) or freshwater tidal zone;
- 2) Undiked and unditched;
- 3) Narrow river-sourced fringing wetland with deep, well-defined tidal channels under the shrub and forest canopy;
- 4) Little freshwater inflow; and
- 5) Surface inundation on higher high tides during most of the year.

Site S11 (Cox Island)

Since restoration site S59 is currently an emergent tidal wetland (tidal marsh), we needed an emergent tidal wetland reference site for comparison. The obvious choice was The Nature Conservancy's Cox Island Preserve (site S11; Map 4), an undiked tidal marsh which is described as one of "Oregon's Greatest Wetlands" by The Wetlands Conservancy (http://www.wetlandsconservancy.org/oregons_greatest.html). Cox Island was thoroughly characterized at the time of its acquisition by The Nature Conservancy (Hoffnagle 1979). In 1979, its vegetation was predominantly low and high marsh, and that remains true in 2009.

We learned from Oregon Natural Heritage Program historic vegetation mapping (Hawes *et al.* 2002) that a large proportion of the site's high marsh was originally Sitka spruce swamp in the 1850's (Appendix 1, Map 3). The trees were probably removed for lumber, and to improve grazing on the site. We recommend exploration of the feasibility of restoring the site's spruce swamp (see "Recommendations for future monitoring"). However, the absence of the original spruce swamp did not reduce the site's value as a reference site for this project, for three reasons. First, based on plant community observation (Appendix 4, Photo A17), we estimated that Cox Island would have a range of elevations that bracket those at restoration site S59. Second, knowing the site once supported Sitka spruce swamp but now supports high marsh gave us an opportunity to evaluate the ecotone (transition zone) between high marsh and tidal swamp. Third, we were interested in considering whether current elevations and salinities might support restoration of tidal swamp at this site – information that might be useful to The Nature Conservancy.

Cox Island has populations of saltmeadow cordgrass (*Spartina patens*), an invasive species native to the east coast. An active control program has been in place for many years. Cordgrass was a small component of vegetation at the site, and we did not find this species in any of our plots. Its presence did not reduce the site's suitability as a reference area.

Site S63

The Siuslaw tidal swamp reference site was site S63 (Map 6), a mix of Sitka spruce tidal swamp and willow tidal swamp. Early site reconnaissance showed diverse native plant communities that appeared undisturbed. Vegetation on the south portion of the site was dominated by brackish-tolerant species and included a Sitka spruce canopy, a shrub layer dominated by black twinberry (with some upland shrubs growing on fallen trees), and a very diverse herbaceous layer (Appendix 4, Photo A8). The north portion of the site was a willow swamp with an understory of slough sedge and skunk cabbage (Appendix 4, Photo A9 and A10). Soil characteristics throughout the site were typical of least-disturbed tidal wetlands (uncompacted, with high organic content); channel morphology was also typical of least-disturbed conditions (steep-sided, narrow and sinuous).

Our first site visit revealed a perimeter dike along the riverbank and a cross-dike separating it from the adjacent diked pasture. However, the perimeter dike had breached naturally in several places. Early conversations with the landowner confirmed that the site was diked many decades ago, but was never under agricultural use. Despite the old dike, the site appeared to be in excellent condition and was deemed a suitable reference area, pending analysis of results. As discussed below, results showed no evidence of major disturbance.

Site Y28

Although site S63 was in excellent natural condition, we realized that the site's remnant dike could potentially affect its value as a reference site. During the early stages of this project, we attempted to gain access to the only two other remnants of tidal swamp in the lower Siuslaw River estuary, but were unsuccessful. Therefore, we added a second, undiked tidal swamp reference site in the Yaquina River estuary (site Y28, Map 8). This site was identified and prioritized during the Yaquina-Alsea tidal wetland prioritization (Brophy 1999). It was never diked; channels were deep, steep-sided and sinuous. Vegetation ranged from high marsh at the south end of the site to forested wetland on the north.

Monitoring at Site Y28 focused on that portion of the site that best matched conditions at the tidal swamp restoration site (the northernmost portion). The section monitored has a very diverse herbaceous layer, and a black twinberry and Pacific crabapple shrub layer. Sitka spruce are found along major tidal channels (Appendix 4, Photo A7) but not in the study plot. The history of Site Y28 was thoroughly researched by Hennessy (2005).

Monitoring program summary

We followed regional and national standards in developing this monitoring program. Key references during initial project planning were Rice *et al.* (2005), Thayer *et al.* (2005), Callaway (2001), Simenstad *et al.* (1991), and Brophy (2007a). Later in the project, we maintained technical liaison with leading tidal wetland scientists in the Columbia River estuary to ensure our

methods were compatible with their comprehensive monitoring guidance, published in 2008 (Roegner *et al.* 2008).

Monitoring program design begins with a conceptual model describing the relationships between controlling factors, ecosystem structure, ecosystem processes, and valued functions. We considered available conceptual models and selected a model developed for tidal wetlands of the Columbia River estuary (Roegner *et al.* 2008). Following guidelines in the references listed above, we focused our monitoring effort on controlling factors – those factors that control site development and therefore underlie all valued wetland functions. We also monitored structural characteristics and biological characteristics, focusing on vegetation, which constitutes a controlling factor for many functions, forms site structure, and performs a suite of valued wetland functions.

Monitoring parameters are listed in Table 2 below.

Table 2. Monitoring parameters

CONTROLLING FACTORS	
Indicator category	Metric(s)
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

This project’s scope of work included vegetation monitoring in summer 2006, and longer monitoring periods for some of the other parameters to address seasonal variability. The monitoring timeline is shown in Table 3.

In addition, as described in “Collaborative and related projects” below, monitoring was expanded and extended at some of the sites through collaborative and related projects funded by other organizations. Restoration and post-restoration effectiveness monitoring at site S65 were funded by the Oregon Department of Transportation as part of their mitigation activities for construction of the North Fork Siuslaw River Bridge. Results of collaborative projects are briefly discussed in

this report; full results can be found in each related project’s report (see “Collaborative and related projects” below for citations).

Table 3. Monitoring timeline. Monitoring activities occurred during the gray time blocks.

Metric	2006			2007		
	spring	summer	fall	winter	spring	summer
Tidal inundation regime						
Wetland surface elevation						
Water table depth						
Surface water salinity						
Soils (all metrics)						
Vegetation (all metrics)						

Methods: Summary

Monitoring methods are documented in the project’s Quality Assurance Program Plan (QAPP) and accepted modifications to that Plan (Appendices 5 and 6). Methods followed regional and national standards (Roegner *et al.* 2008, Thayer *et al.* 2005, Rice *et al.* 2005, Simenstad *et al.* 1991) and were compatible with the most complete set of protocols developed recently in our region (Roegner *et al.* 2008).

Monitoring methods are summarized in Table 4. The sections following Table 4 contain additional details for methods that were not completely described in the QAPP. However, the QAPP remains the central reference for methods used in this project.

Table 4. Summary of monitoring methods

Metric	Method/equipment	Frequency and timing	Sample location	Analysis methods
Wetland surface elevation	Laser level	Measured once in spring 2007	Endpoints of permanent study plots; additional topographic features as time permits	Convert measurements to NAVD88 and MLLW datums via ties to benchmarks and tide station elevations. Calculate average elevation for each plot and use results to calculate tidal inundation regime.
Tidal inundation regime	Electronic water level logger (“tide gauge”)	15min logging interval; logged during summer 2006	Main tidal channel near site	Model water levels, incorporating river flow effects for Siuslaw tidal swamp sites. Derive inundation frequency and duration from analysis of modeled water levels compared to wetland surface elevations; compare sites.
Water table depth	Manual measurement; automated logging for 1-2 mo	Weekly or biweekly for spring-summer 2007	Shallow observation well near each study plot (forested and scrub-shrub wetland sites only)	Compare levels at reference and restoration sites at each observation date; compare seasonal patterns. Determine whether tides influence groundwater levels.
Surface water salinity	Refractometer	Grab sample, summer and winter	Top 30cm of surface water in a tidal channel near each study plot	Classify salinity regime; compare salinity at reference and restoration sites at each sample date.
Soil organic matter content	% organic matter by loss on ignition	Sampled once in fall 2006	Multiple soil cores bulked from root zone (upper 30cm) in each study plot	Compare restoration & reference sites
Soil salinity/ electrical conductivity	Electrical conductivity of soil solution (conductivity probe)	Sampled once in fall 2006	Multiple soil cores bulked from root zone (upper 30cm) in each study plot	Compare restoration & reference sites
Soil pH	pH of soil solution (pH probe)	Sampled once in fall 2006	Multiple soil cores bulked from root zone (upper 30cm) in each study plot	Compare restoration & reference sites
Soil texture	% sand, silt and clay	Sampled once in fall 2006	Multiple soil cores bulked from root zone (upper 30cm) in each study plot	Compare restoration & reference sites
Plant community composition	% cover by species	Sampled once in summer 2006	Permanent study plots representing major plant communities; randomized sampling within plots	Calculate average % cover by plot, species richness. Compare restoration & reference sites via t-tests, diversity indices.
Woody plant density	Stems/ha	Sampled once in summer 2006	Permanent study plots (see above)	Compare restoration and reference sites via t-test.
Tree basal area	sq ft/acre	Sampled once in summer 2006	Permanent study plots (see above)	Compare restoration and reference sites via t-test.
Habitat class interspersion	Interspersion class (from aerial photos)	Based on 2005 aerials	Entire site	Classify, using categories in Adamus <i>et al.</i> (2009)
Slope	Laser level	Measured once in spring 2007	Entire site	Calculate % slope between lowest and highest measured points on site
Aspect	Airphoto interpretation	Based on 2005 aerials	Entire site	Determine compass direction for tidal inflow
Geomorphic setting	Airphoto interpretation	Based on 2005 aerials	Entire site	Classify, using categories in Adamus (2005)

Methods: Details not covered in QAPP

Sampling design

As described in the QAPP (Appendices 5 and 6), monitoring was focused on permanent plots established and sampled following a stratified random sampling method, as recommended in national and regional monitoring guidance (Roegner *et al.* 2008, Thayer *et al.* 2005, Rice *et al.* 2005, Simenstad *et al.* 1991). We conducted initial site reconnaissance in 2006 to identify major elevation/tidal inundation zones (strata) within each site. We established 18 permanent study plots within these strata, in internally homogeneous areas representative of the major plant communities on each site. The intent of this stratified sampling design was to characterize typical conditions within the strata that represent the bulk of each site, and to allow statistical comparison of change over time within these strata.

Study plots were generally 30 by 150 ft, but some plots were smaller in order to allow placement within homogeneous strata (Table 5). Locations of study plots are shown in Maps 4-8 (Appendix 1). Details on placement are provided below.

Site S11 (Cox Island)

Study plots (Map 4) were established in high marsh (P1, P2) and low marsh (P3) in an attempt to bracket current and historic conditions at site S59. Both high marsh plots were in areas that were historically Sitka spruce swamp according to Hawes *et al.* (2002). Additional elevation measurements were taken on the highest ground on the site (east of P1).

Site S59

Study plots are shown in Map 5. Plot P1 was established on the highest portion of the site, in an area vegetated by Lyngbye's sedge (*Carex lyngbyei*) and softstem bulrush (*Schoenoplectus tabernaemontani*). Plot P2 was placed in a dense stand of Lyngbye's sedge typical of the vegetation developing on much of the site. Plot P3 is in the narrow northern section of the site, characterized by extensive mats of creeping bentgrass (*Agrostis stolonifera*).

Site S63

At site S63, one study plot was established in each of the site's two main subareas (Map 6): Hooker willow swamp on the north half (P1), and Sitka spruce swamp on the south half (P2).

Site S65

Study plots are shown in Map 7. Study Plot P1 was established in a nearly solid stand of reed canarygrass (*Phalaris arundinacea*), typical of the lower portion of the pasture to be restored. Plots P2 and P3 were each half the usual width, and were established using a slightly different approach from that used at the other study sites: They were adjacent and the border between the two plots coincided with the border of willow stand along the site's main drainage ditch. Plot P2

was entirely within the willow stand; by contrast, P3 was heavily dominated by reed canarygrass. We intended these two plots to allow detection of change within each plot but also to allow tracking of the expansion of the willow stand. Plot P4 was established in 2007 as part of the related mitigation project funded by ODOT (see “Collaborative and related projects” below). Like P1 and P3, P4 was dominated by reed canarygrass when the plot was established. However, its elevation is significantly higher than P1, so this plot will allow determination of restoration trajectory on the higher portions of the old pasture.

Site Y28

Site Y28 has been studied over the course of several projects since 1999; five study plots have been established on the site. Four of these have emergent vegetation; the farthest north plot (P5, Map 8) was the only plot located in an area of tidal swamp suitable as a reference area for site S65. Therefore, data from P5 were used in this study. Notably, since P5 is in scrub-shrub tidal wetland, tree cover was lacking. However, the historic and current wetland classes for Site Y28 include estuarine forested wetlands, because many large Sitka spruce are found along channels on the site. These spruce areas were too small for establishment of an adequately sized study plot.

Table 5. Study plot sizes

Site	Plot	Width (ft)	Length (ft)
S11	P1	30	150
	P2	30	150
	P3	30	150
S59	P1	30	150
	P2	30	150
	P3	30	150
S63	P1	30	150
	P2	30	120
S65	P1	30	135
	P2	15	135
	P3	15	135
	P4	30	150
Y28	P5	30	150

Elevation survey methods

Elevation surveys were conducted by several groups using several different methods:

- 1) Dr. Ray Weldon’s team from the University of Oregon surveyed tide gauge elevations and local benchmarks at site S63 and S65. Their team used survey grade GPS equipment and simultaneous occupation of a USGS benchmark near Florence (J87 Reset) and a local benchmark (“S63 utility pole”) to accurately tie elevations to NAVD88.

2) A survey crew from the Oregon Department of Transportation used GPS equipment to survey elevations at Sites S63 and S65 in fall 2006.

3) Laura Brophy (Green Point Consulting) and Jeff Jones (Amythyst Enterprises) used a laser level to survey study plots at sites S11 (Cox Island), S59 and Y28. We also measured elevations of other site features and instrumentation. The water tie method was used to tie elevations of study plots and other site features to benchmarks of known elevation in the NAVD88 reference frame.

4) Laura Brophy and Oregon State University graduate student Rebecca Tully surveyed the elevation of the tide gauge at Site Y28 using a laser level and tying to elevation points established during the Jones-Brophy survey.

Elevation datums

In “Results and discussion” below, we express wetland elevations relative to three different “datums”: NAVD88, MLLW and MHHW. To understand these datums, basic knowledge of Oregon tide cycles is needed; this information is provided in Good (1999) and Brophy (2007a). Gill and Schulz (2001) provide detailed information on elevation datums and their uses.

Briefly, NAVD88 is a fixed *geodetic datum* and is the official vertical reference datum for the United States (Gill and Schulz 2001); it is a reference elevation that is consistent across the entire country. MLLW (mean lower low water) is the average of the lower of the two low tides each day, across many years of tide records. MHHW (mean higher high water) is the average of the higher of two high tides each day. MLLW and MHHW are *tidal datums*; their absolute height varies from place to place depending on prevailing winds, currents, and other factors. In addition, changing sea levels and land levels (subsidence or uplift) alter the relationships between MLLW and the land surface. Thus, the relationship between tidal elevations (MLLW) and geodetic datums (NGVD29, NAVD88) varies from place to place and over time. For best accuracy, MLLW should be calculated locally from local tide records. We calculated MLLW and MHHW from tide height data collected at or near our study sites.

Elevations referenced to a tidal datum (generally MLLW) are required for studies of tidal wetland ecology, because these elevations express heights in a way that relates consistently and mathematically to inundation regimes. However, elevations should also be expressed relative to the geodetic datum (NAVD88) for consistency with established benchmarks, engineering plans, and restoration designs in other areas. The U.S. Army Corps of Engineers (1995) states that “On [coastal] project maps and documentation, all tidal datums must be clearly related to the fixed national survey datums.”

In addition to the MLLW datum we also express elevations in relation to a different tidal datum, “mean higher high water” (abbreviated MHHW). The main reason for using MHHW in addition to MLLW is that MLLW cannot be calculated if tide gauge is located above the lowest tide level. This is often the case for tide gauges installed in tidal channels within tidal wetlands, which generally empty at low tide. In addition, since some of Oregon’s most distinctive tidal wetland types (high marsh and tidal swamp) are found near or above the elevation of MHHW, MHHW is

a useful reference point for understanding tidal inundation regimes and in fact may better express tidal inundation than the MLLW datum. For these reasons, we feel that expressing tidal wetland elevations in terms of MHHW (as well as MLLW, where possible) can assist in restoration design and planning.

Tidal inundation regime, tidal datums, and the “river flow effect”

General methods for determining tidal inundation regimes at study sites are described in Appendices 5 and 6 (QAPP and Modifications to QAPP). Additional details are provided below for innovative methods developed and implemented during the course of the study.

North Fork Siuslaw River sites (S59, S63, and S65)

We calculated and/or modeled tidal inundation regimes for study sites with the help of Dr. Ray Weldon at the University of Oregon Geosciences Department. Weldon installed a water level recorder (“tide gauge”) on the North Fork Siuslaw River just south of site S63, collected data, and modeled water levels for the North Fork. We used the results of Weldon’s modeling to calculate tidal inundation regimes for each plot at Sites S59, S63, and S65.

Weldon calculated tidal datums using the master station method (NOAA 2003), with South Beach as the master station. However, Weldon’s work has highlighted the importance of incorporating the added water heights caused by river flows – the “*river flow effect*” or *fluvial component* of a site’s inundation regime. The river flow effect is prominent in many Oregon estuaries including the Siuslaw. In many of our estuaries, winter precipitation and high-gradient watersheds create high peak flows that significantly raise water levels above those created by tides alone (Appendix 4, Photos A12 and A13). Substantial added water heights due to river flow are seen not only in winter, but also in fall and spring. The “river flow effect” is particularly strong in the middle and upper zones of the estuary, where the river valley is relatively narrow (so flood peaks are high), and tidal influence is still strong.

Interactions between river flows and tides in the Columbia River estuary have been modeled using continuous wavelet transform methods (Jay and Kukulka 2003). However, a simpler and more “user-friendly” approach was used by Weldon to model the fluvial component of the inundation regime for our study areas (Ray Weldon, personal communication, 2006-2008):

1. Detide the measured flow data from the observation period at the site of interest.
2. Obtain river discharge data for the observation period from a river gauge station located above head of tide.
3. Calculate normalized discharge for the observation period by subtracting average summer low discharge from each flow value.
4. Plot the detided flow data against the normalized, log₁₀-transformed river discharge data for the observation period.
5. Conduct a linear regression of the relationship between detided flow data and normalized log₁₀-transformed river discharge data. The linear regression formula is the “river flow effect.”
6. Obtain a longterm record of river flows (e.g., 100 years) and determine the 5th, 50th, and 95th percentile flow values for each day of the year.

7. Apply the regression formula to the 5th, 50th and 95th percentile river flow values for each day to obtain three “flow adjustment” values for each day of the year.
8. Add the three “flow adjustment” values to the predicted tide height from the master station method to get predicted water height for each flow scenario for each day of the year.

The steps above model water levels not only during typical river flows (50th percentile), but also during the high river flow events that are important controlling factors in tidal wetland development in the middle and upper estuary. High natural levees in these areas indicate longterm patterns of alluvial sediment deposition during bank overtopping events. Channel formation processes in these upper estuary sites are likely to be tightly coupled to high river flow events, since wetland elevations are relatively high in the tide range. Thus, to improve our understanding of controlling factors at our study sites, we needed to model water heights during high flow scenarios as well as median flows.

Weldon’s calculations also included tidal datums such as Mean Lower Low Water (MLLW) and Mean Higher High Water (MHHW) for these sites. These datums allowed us to calculate the “tidal elevation” of the wetlands – that is, the elevation of the wetland surface relative to tidal datums such as MHHW.

In addition to the modeling described above, we were able to conduct longterm water level monitoring through a related project funded by the Oregon Department of Transportation as part of mitigation for the new North Fork Siuslaw River Bridge. Continuous water level monitoring at Sites S63 and S65 began in fall 2007 and will continue through fall 2009. Results are described briefly in this report; for full results, see Brophy (2007b, 2008).

Yaquina tidal swamp (Site Y28)

In a related project funded by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), we installed a tide gauge at Site Y28, calculated the tidal inundation regime using a full year of on-site water level observations, modeled tidal inundation using the master station method, and calculated tidal datums for Site Y28. The CICEET project was greatly assisted by NOAA’s Center for Operational Oceanographic Products and Services (CO-OPS). Our collaborators at CO-OPS calculated tidal datums and tidal inundation regime for this site using the master station method. As of the production of this report, CO-OPS is calculating river flow effects to achieve an integrated inundation model. Results from the CICEET project are described briefly in this report and in Brophy *et al.* (2008, 2009), and will be fully described in the CICEET project final report (Brophy *et al.*, in preparation).

Site S11 (Cox Island)

The tidal inundation regime at site S11 was calculated using a full year of water level data obtained and provided to us by Weldon. These data were collected by NOAA at the Florence tide gauge during 1933-34, and represent the only longterm NOAA tide gauge record from the

Siuslaw basin. Although the ideal method of using these data would have been to model the river flow effect as described above, time limitations prevented application of this method; we simply used the data “as is” to approximate a likely tidal inundation regime for site S11. Weldon also provided the NAVD88 elevation of the Florence NOAA gauge, which allowed us to tie the 1933 water level record to the elevations of our study plots, which were also tied to NAVD88. Dr. Weldon and NOAA-CO-OPS provided tidal datum elevations in NAVD88, allowing us to calculate the tidal elevation of our study plots at Cox Island.

Tidal inundation regime metrics

Tidal inundation regimes have generally been described in terms of duration and frequency of inundation during the observation period. For example, commonly used metrics are “percent inundation” or “hours of inundation.” However, we felt such metrics would not be useful to many practitioners who think in terms of how often a site “floods” with the tides. Therefore, along with percent inundation, we calculated an additional inundation regime metric – “days with inundation events” (Appendix 2, Figures A1-A5). A particular day is considered to have an “inundation event” if the wetland surface inundates for any length of time that day. This metric is easily understood by those who spend time in tidal wetlands; it clearly shows whether the tides inundate a site for a few days each month, every day, or somewhere in between these extremes. The “inundation events” metric also allows quick understanding of how a site’s inundation regime relates to lunar cycles: a site that inundates only 5 or 6 days a month is inundating only on new and full moons (spring tide cycles), whereas a site that inundates 20 days a month is inundating during quarter moons (neap tides) as well as spring tides.

We also calculated the inundation regime separately for each month of the year, because we expected inundation to be more frequent in winter months. Averaging inundation frequency or duration across the year would obscure important site differences.

Groundwater fluctuation

We installed and monitored shallow observation wells as described in the QAPP. Shallow observation wells integrate groundwater levels throughout the depth of the well (in our case, about 3 ft below the soil surface). The terms “groundwater level” and “water table depth” are used interchangeably in this report. Five wells were installed, one near each study plot at the three tidal swamp sites (S63, S65, and Y28). Site S65 was not yet restored during the groundwater monitoring period, so it had no active tidal channels.

For the tidal swamp reference sites (S63 and Y28), the distance from each groundwater well to the nearest tidal channel varied, but was always over 20 ft. Groundwater levels and groundwater responses to tidal cycles undoubtedly vary with the distance to tidal channels, but the varying distances were not considered a problem because our primary goal was to characterize broad seasonal trends in groundwater level. To avoid masking of seasonal changes by tidal fluctuations, the weekly manual water level checks that were used to characterize seasonal changes in groundwater level were always conducted at low tide.

As described in the QAPP, we also collected groundwater data at more frequent intervals using automated water level loggers (Onset HOBO loggers, U20 model) for at least one spring tide cycle. The purpose of the brief automated logging period was simply to determine whether groundwater levels responded to tide cycles. Full analysis of groundwater–tide interactions was beyond the scope of this study, but a related project (Brophy *et al.* 2008, 2009; Brophy *et al.*, in preparation) included automated logging of groundwater levels for a full year at Site Y28.

Surface water salinity

Summer measurements of surface water salinity were taken in August; winter measurements in January through March. Salinity was measured in the tidal channel closest to each plot. As described in the QAPP, paired measurements were taken within 24 hours at restoration and reference sites. Tide stage at the time of measurement varied; measured salinities did not vary by tide stage, so measurements from all tide stages were averaged. Site S65 was not yet restored during these measurements and had very limited tidal exchange through its highly restrictive culvert. Salinity grab samples were taken just inside and outside the restrictive culvert at the site's main ditch (near P2/3).

Vegetation

Mapping of major vegetation types

The formal scope of work for this project did not include vegetation mapping. However, we felt that a small investment of time creating simple maps of major vegetation types would facilitate future evaluation of restoration trajectory at the restoration sites. We used existing data and field observations to create these maps. The best existing GIS data source was the map of known and potential tidal wetlands created by Russell Scranton during development of the Hydrogeomorphic Assessment Method for tidal wetlands of Oregon (Scranton 2004). Our field observations, combined with high-resolution color infrared aerial orthophotos provided by the Oregon Department of Land Conservation and Development and the U.S. Environmental Protection Agency, allowed us to evaluate and update Scranton's maps. We found that Scranton's map could be used "as is" to map vegetated areas and mud flats at site S59. We slightly revised Scranton's map for site S65 to more accurately map the two main vegetation types there -- reed canarygrass and scrub-shrub/forested wetlands.

Plant community composition

To compare plant community composition at restoration and reference sites, we used the Student's t-statistic (Steel and Torrie 1980) and the similarity index (Thom *et al.* 2002), a measure of beta diversity. Since these calculations are time-consuming, we focused on the most meaningful "apple to apple" comparisons -- that is, we compared the permanent plots at a given restoration site to the reference plot that was most similar in elevation and salinity zone and

therefore had similar levels of the major ecosystem “drivers” or controlling factors (tidal hydrology and salinity). These comparisons were:

- All plots at site S59 (2 to 2.5 ft below MHHW) vs. site S11 Plot 3 (1 ft below MHHW)
- All plots at site S65 (0.6 to 1.5 ft above MHHW) vs. site S63 Plot 2 (0.5 ft above MHHW)

Comparisons of restoration sites to their historic conditions would also be interesting, but similarity would clearly be very low at this time (see “Discussion: Vegetation” below). We recommend such comparisons be initiated later in the restoration trajectory, when the restoration sites have begun to show more similarity to historic conditions (see “Recommendations for future monitoring” below).

For t-test comparisons of plant species cover between restoration and reference sites, we used data from randomized subplots as replicates. Comparisons were made for any species that was present in both restoration and reference plots and for which average cover exceeded 5% in any plot. Species present at less than 5% cover were compared using similarity indices (see below), which compare overall species diversity.

Species richness was calculated as the number of species present within each plot. We also calculated species richness for each site as a whole, but this value is highly dependent on the number of elevation zones within a site and therefore may not provide the most useful comparison between sites.

Plant species diversity was calculated using weighted and unweighted similarity indices (Thom *et al.* 2002). The similarity index is a measure of “beta diversity” (McCune and Grace 2002); it compares the number of species unique to each of two plant communities. The higher the similarity index, the more similar the communities are. The unweighted similarity index is based on the intersection of species between two plant communities. The weighted similarity index incorporates percent cover data, providing more information on plant community composition. We used both weighted and unweighted similarity indices to compare restoration sites to the appropriate reference plots.

Although this project only included a single year of monitoring, the North Fork Bridge mitigation project (Brophy 2007b, 2008) allowed us to repeat the plant community monitoring at site S65 during 2008. We used t-tests to compare percent cover between 2006 and 2008 for dominant species. We also recalculated the weighted and unweighted similarity indices for the 2008 vegetation data at S65. Since the bridge mitigation project did not include vegetation monitoring at S63 in 2008, we were only able to compare the 2008 data at S65 to the 2006 reference site data. This comparison does not account for possible changes in vegetation at the reference site between 2006 and 2008, but field observations at the reference site in 2008 did not reveal any obvious changes.

Landscape setting

Habitat class interspersion

Interspersion is a way of describing complexity of habitat structure. Wetlands with high habitat class interspersion are expected to perform certain wetland functions at a higher level than those with low interspersion (Adamus *et al.* 2009). For this study, we classified interspersion by viewing high-resolution aerial photographs of each site and categorizing patch size and degree of intermingling of different wetland classes. Classes used were “water/mud,” which we used for tidal channels, mud flats, and other bare substrate (or nonvascular vegetation) areas that inundate on every high tide; plus three classes defined in Cowardin (1979): emergent (low growing herbaceous vegetation), scrub-shrub (woody vegetation up to 6m tall) and forested (woody vegetation over 6m tall). Since interspersion is a characteristic of an entire wetland, we classified interspersion for the entire wetland associated with each study site rather than for study plots or sites *per se*.

We used the following habitat interspersion categories, adapted from Adamus *et al.* 2009:

High interspersion: many small patches of different habitat classes are intermingled

Medium interspersion: a few (3-5) patches of different habitat classes are intermingled

Low interspersion: habitat classes present in single large blocks; little intermingling

Slope

Site slope was calculated from the lowest and highest surveyed points across the width of the wetland (excluding dikes). All sites had very low slope (under 0.5%), which is typical of Oregon tidal wetlands.

Aspect

As described by Adamus (2005), aspect is the “compass direction to which most of a wetland’s water drains.” We determined aspect from aerial photos.

Geomorphic setting

We placed each study site within the geomorphic classification used in Adamus *et al.* (2005). Classes encountered in this study were channel fringe shore wetlands (wetlands located outside the broad embayments of the lower estuary, with the majority of their perimeter along channels) and bay fringe island wetlands (located in the lower bay and entirely surrounded by water).

Results

Elevation

Elevations for study plots and other site features are shown in Tables 6 and 7 below. As described in “Methods” above, elevations are shown relative to both tidal datums (MLLW, MHHW) and geodetic datum (NAVD88). Average elevation of each study plot was calculated from the endpoints of the plot’s central axis.

Table 6. Elevations of study plots. Shading: blue = tidal marsh reference site; yellow = restoration sites; green = tidal swamp reference sites.

Site	Plot	Average elevation (ft MLLW)	Average elevation (ft MHHW)	Average elevation (ft NAVD88)	Data source
S11	1	7.58	0.38	7.47	Jones-Brophy survey
S11	2	7.63	0.43	7.52	Jones-Brophy survey
S11	3	6.18	-1.02	6.07	Jones-Brophy survey
S59	1	5.28	-1.98	5.12	Jones-Brophy survey
S59	2	4.84	-2.41	4.68	Jones-Brophy survey
S59	3	4.78	-2.48	4.61	Jones-Brophy survey
S63	1	7.00	-0.26	6.84	ODOT survey
S63	2	7.76	0.51	7.60	ODOT survey
S65	1	7.82	0.57	7.66	ODOT survey
S65	2/3*	7.97	0.72	7.81	ODOT survey
S65	4	8.76	1.51	8.60	ODOT survey
Y28	5	not det.	0.66	8.65	Jones-Brophy survey

* S65 plots 2 and 3 shared a central axis and thus had the same measured elevation.

Table 7. Elevations of site features and instrumentation.

Elevation point type and description	Elevation (ft NAVD88)	Elevation (ft MLLW)	Elevation (ft MHHW)	Source
TIDE GAUGES				
Weldon tide gauge sensor	1.92	2.08	-5.17	Weldon survey
S63 HOBO tide gauge sensor	2.85	3.01	-4.24	Jones-Brophy survey
S65 top of LOC1 HOBO t-post	7.50	7.66	0.41	Jones-Brophy survey
S65 LOC1 HOBO tide gauge sensor	6.41	6.57	-0.68	Jones-Brophy survey
S65 top of LOC2 HOBO t-post	6.89	7.05	-0.20	Jones-Brophy survey
S65 LOC2 HOBO tide gauge sensor	5.41	5.57	-1.68	Jones-Brophy survey
LOCAL BENCHMARKS				
Local benchmark, S63 tide gate	4.82	4.98	-2.27	Weldon survey
Local benchmark, S63 utility pole	21.90	22.06	14.81	Weldon survey
top of rebar high tide marker set by Jones in 6/06	7.68	7.84	0.59	ODOT survey
ODOT benchmark 100 at S65	7.91	8.07	0.82	ODOT survey
ODOT benchmark 101 at S65	8.19	8.35	1.10	ODOT survey

Elevation point type and description	Elevation (ft NAVD88)	Elevation (ft MLLW)	Elevation (ft MHHW)	Source
OTHER SITE FEATURES, SITE S11				
high natural levee, east margin of island	7.83	7.94	0.74	Jones-Brophy survey
high natural levee, east margin of island	7.97	8.08	0.87	Jones-Brophy survey
CARLYN bench outside east natural levee	6.81	6.92	-0.28	Jones-Brophy survey
OTHER SITE FEATURES, SITE S63				
S63 main tidal channel flow path near mouth	0.96	1.12	-6.13	ODOT survey
OTHER SITE FEATURES, SITE S65				
typical Ditch A flow path, S65	5.76	5.92	-1.33	ODOT survey
restrictive wood culvert flow path, S65	2.59	2.75	-4.50	ODOT survey
Culvert C (east side of river bend) flow path	3.96	4.12	-3.13	Jones survey
Ditch C about 75' from riverbank - flow path	6.38	6.54	-0.71	Jones survey
S65 forested wetland, 415346E 4873980N (WGS84)	7.01	7.17	-0.08	Jones survey
S65 forested wetland, 415350E 4873959N (WGS84)	7.01	7.17	-0.08	Jones survey
S65 forested wetland, 415371E 4874004N (WGS84)	6.25	6.41	-0.84	Jones survey
typical dike elevation	9.36	9.52	2.27	ODOT survey
OTHER SITE FEATURES, SITE Y28				
Tidal channel temp benchmark	11.10	not det'd	3.11	Jones-Brophy survey
Spruce root platform above main channel	9.96	not det'd	1.97	Jones-Brophy survey
HOBO tide gauge sensor	4.48	not det'd	-3.51	Brophy-Tully survey

Hydrology

Tidal inundation regime and the “river flow effect”

Graphics illustrating tidal inundation regimes for study sites are provided in Appendix 2, Figures A1-A15. Figures A12 through A15 illustrate the “river flow effect” (fluvial influence on tidal inundation regime) for Sites S63 and S65.

Tidal datums

Tidal datums from tide gauges (located on or near each site) are provided in Table 8.

Table 8. Tidal datums for study sites

Site	Highest observed tide*	MHHW	MHW	MSL	MLW	MLLW	Tide gauge location
S11 (Cox Island)	10.39	7.09	6.39	3.69	0.99	-0.11	Florence
S59, S63, and S65	10.50	7.09	6.50	3.71	1.04	-0.16	400 ft S of site S63
Y28	10.55	7.99	7.26				Site Y28

* Highest observed tide during 1 yr observation period (S11: 1933-34; S59, S63 and S65: 2006-2007; Y28: 2007-2008)

Groundwater fluctuation

Figure 1 illustrates water table depth at the tidal swamp restoration site (S65) and reference sites (S63 and Y28) during March through June 2006. The data in Figure 1 were obtained from manual water level measurements in groundwater wells; data were collected once a week near low tide. Site S65 had not yet been restored during this observation period, and it had very little tidal influence due to highly restrictive culverts.

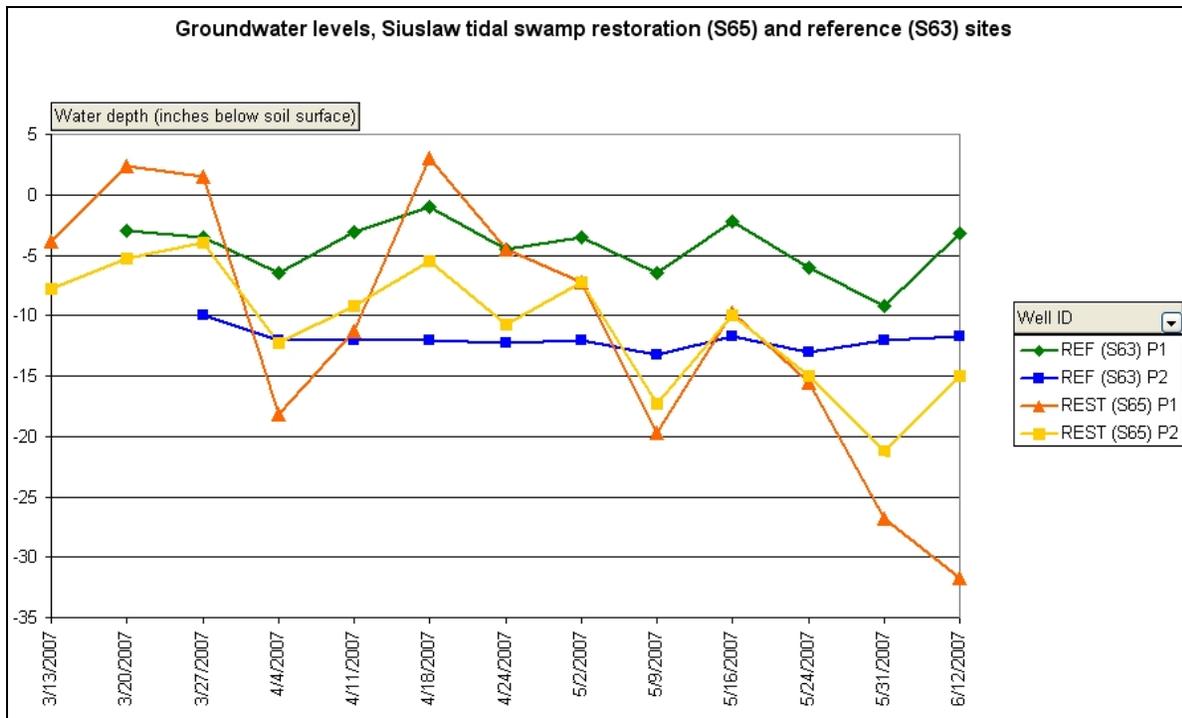


Figure 1. Water table depth in March to June 2007 at tidal swamp restoration site S65 (pre-restoration) and reference site S63.

Figures 2 through 5 illustrate tidal influence on groundwater levels at Sites S63, S65 and Y28. Data were recorded at 15 min intervals using automated level loggers placed in shallow observation wells. As described in the QAPP, the observation period for this portion of the study was brief -- one or more spring tide cycles -- because the goal was simply to determine whether groundwater levels responded to tidal influence. Tide heights from Site Y28 were used for comparison to groundwater data from Sites S63 and S65, because there was no tide gauge present on the North Fork Siuslaw River during the observation period.

In these graphs, water levels are shown relative to the soil surface, which is at zero on the groundwater level axis. Unscaled tide heights at Site Y28 are shown to allow visual comparison of timing of peaks. These graphs are intended to illustrate the close temporal relationship between time of high tide and time of high groundwater. Full analysis of groundwater level – tide interactions was beyond the scope of this study.

On the groundwater axis, a horizontal gray line shows the soil surface (zero on the groundwater level scale). Wetlands generally have a water table within the top 12 inches of soil (at least seasonally).

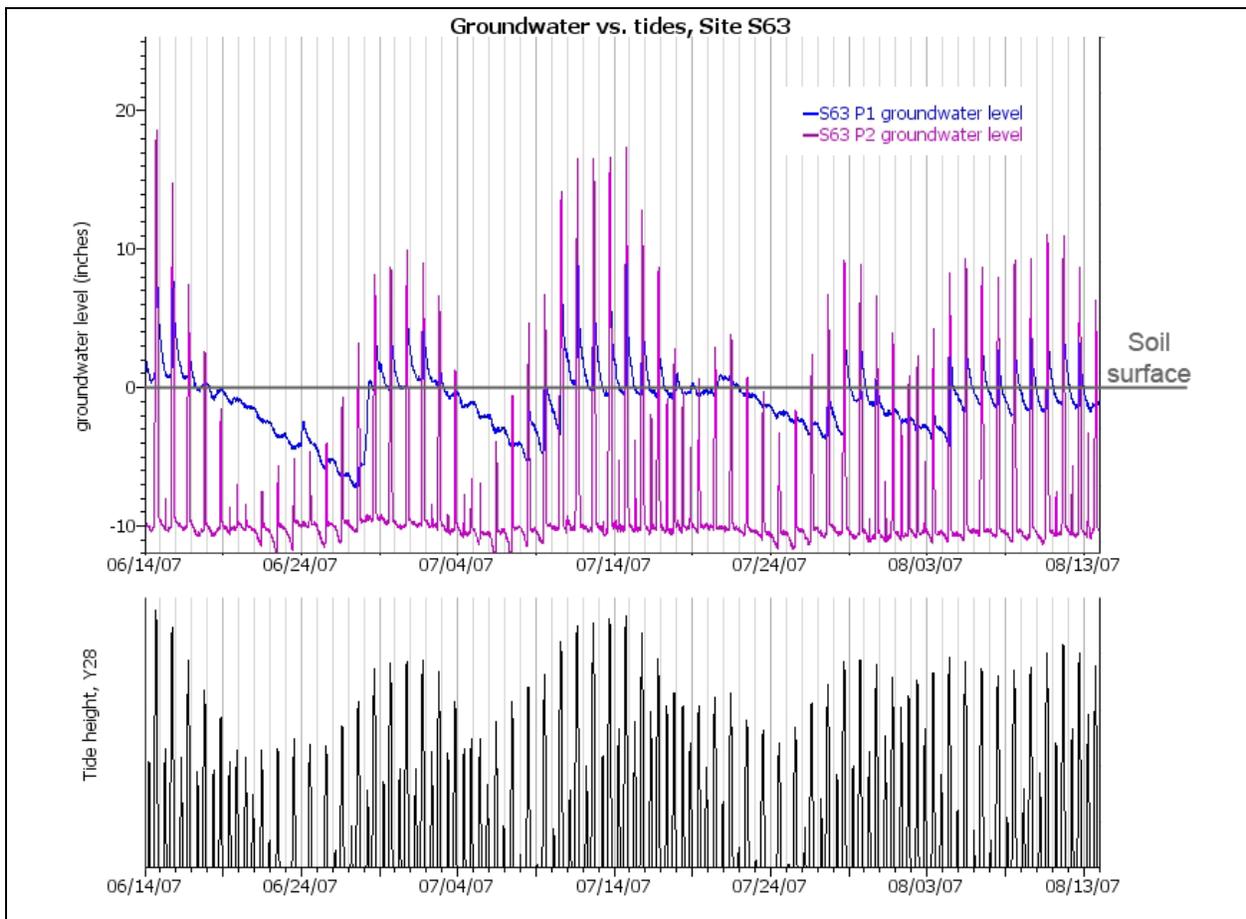


Figure 2. Groundwater fluctuation vs. tide cycles at tidal swamp reference site S63, June-July 2007.

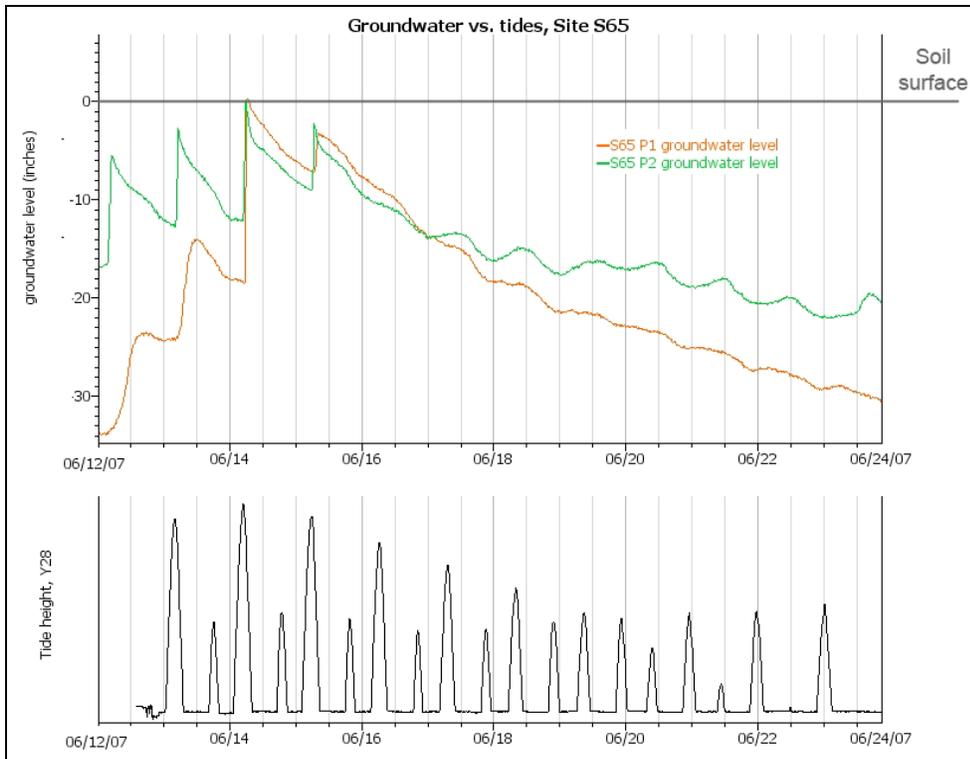


Figure 3. Groundwater fluctuation vs. tide cycles at tidal swamp restoration site S65.

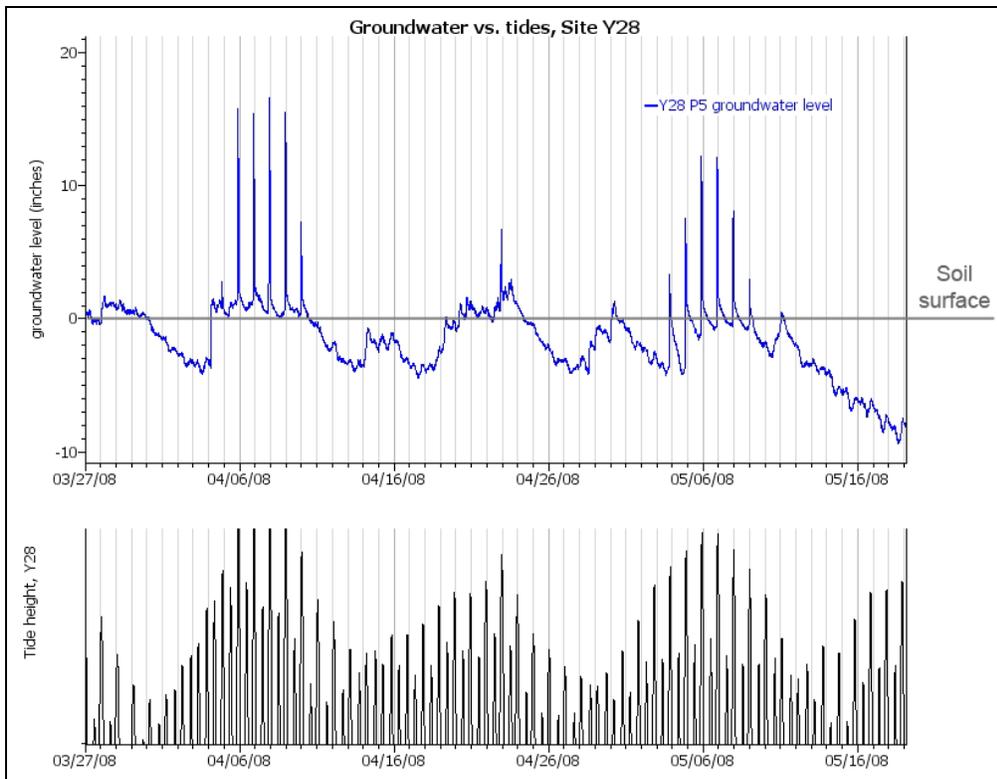


Figure 4. Groundwater fluctuation vs. tide cycles at tidal swamp reference site Y28, spring.

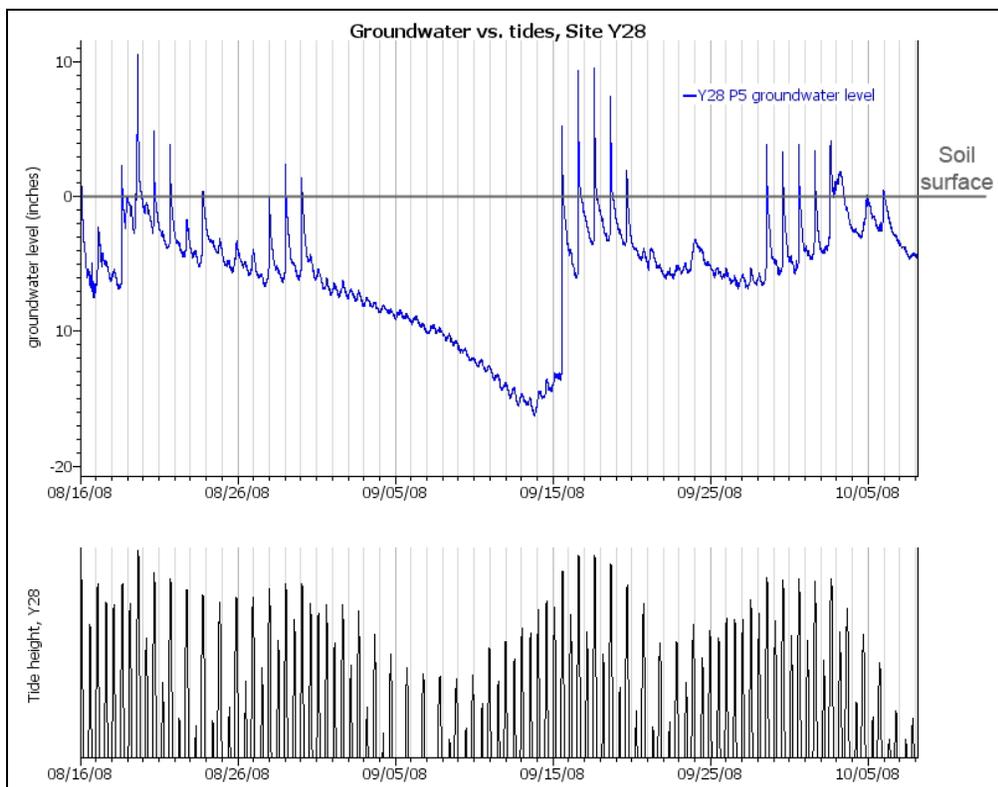


Figure 5. Groundwater fluctuation vs. tide cycles at tidal swamp reference site Y28, late summer.

Surface water salinity

Summer and winter surface water salinities are shown in Table 9.

Table 9. Average surface water salinity at study sites (grab sample, refractometer reading). Shading: blue = tidal marsh reference site; yellow = restoration sites; green = tidal swamp reference sites.

Site	Plot	Site type	Average summer salinity (ppt)	Average winter salinity (ppt)
S11	P1	reference	19.0	5.0
S11	P2	reference	19.0	2.5
S11	P3	reference	20.0	3.5
S59	P1	restoration	11.7	4.0
S59	P2	restoration	8.5	4.0
S59	P3	restoration	9.0	3.0
S63	P1	reference	3.5	2.0
S63	P2	reference	6.5	2.0
S65	all	restoration	1.7	0.0
Y28	P5	reference	14.3	0.0

Soils

Soil test results are shown in Table 10. Soils were not sampled at site S65 Plot 4, because this plot was monitored under a separate project for which the scope of work did not include soil analysis.

Table 10. Soil test results from study sites (bulked random sample from surface rooting zone, 0-30cm). Shading: **blue** = tidal marsh reference site; **yellow** = restoration sites; **green** = tidal swamp reference sites.

Site	Plot	Site type	% sand	% silt	% clay	Texture class	pH	%OM (LOI) ¹	% C ²	Is soil a histosol? ³	EC (mS/cm) ⁴	salinity (ppt) ⁵
S11	P1	reference	52.5	32.5	15.0	sandy loam	5.9	9.29	5.4	N	23.0	14.7
S11	P2	reference	36.7	43.3	20.0	loam	5.1	23.37	13.6	N	25.4	16.3
S11	P3	reference	n/a ⁶	n/a ⁶	n/a ⁶	n/a ⁶	6.3	27.59	16.0	Y	39.7	25.4
S59	P1	restoration	37.5	35.0	27.5	clay loam	5.3	25.76	14.9	Y	18.9	12.1
S59	P2	restoration	22.5	50.0	27.5	clay loam	5.4	16.51	9.6	N	18.0	11.5
S59	P3	restoration	39.5	35.6	25.0	loam	5.4	33.98	19.7	Y	15.8	10.1
S63	P1	reference	35.0	48.8	16.3	loam	4.7	45.14	26.2	Y	16.2	10.4
S63	P2	reference	36.3	46.3	17.5	loam	4.6	25.58	14.8	Y	20.4	13.1
S65	P1	restoration	1.7	65.0	33.3	silty clay loam	4.9	14.26	8.3	N	2.0	1.3
S65	P2	restoration	36.7	38.3	25.0	loam	5.1	10.89	6.3	N	1.2	0.8
S65	P3	restoration	30.0	40.0	30.0	clay loam	5.1	12.54	7.3	N	1.2	0.8
Y28	P5	reference	26.7	45.0	28.3	clay loam	4.7	21.91	12.7	N	26.1	16.7

¹ %OM (% organic matter) was determined by loss on ignition (LOI)

² %C (% organic carbon) was derived from % organic matter (%OM) using the formula %C=%OM/1.724

³ Soils were classified as histosols according to methods in Soil Survey Staff (1992)

⁴ EC = electrical conductivity of soil solution

⁵ Salinity of the soil solution was derived from electrical conductivity using the formula salinity = EC*0.64

⁶ High organic content in the soil at S11 P3 prevented determination of particle size distribution.

Vegetation

Vegetation mapping

As described in “Methods: Vegetation mapping” above, we went beyond the planned scope of work to map major vegetation types at the two restoration sites. Boundaries of vegetation classes were taken directly from Scranton (2004) for site S59 (Appendix 1, Map 10). Forty acres (54%) of the site is vegetated by tidal marsh; the other 34A (46%) consists of mud flats (mapped as “water” in Scranton 2004).

For site S65, we used heads-up digitization on a high-resolution aerial orthophoto base to revise Scranton’s map and more accurately show vegetation type boundaries prior to restoration (Appendix 1, Map 11). At this site, 5.1A consisted of a nearly solid stand of reed canarygrass; the remaining 7A had more diverse scrub-shrub and forested vegetation.

Plant community composition

Tables 11 through 13 and Figures A16 through A19 (Appendix 2) summarize plant community composition within study plots. Results for paired restoration and reference sites are presented together. For comparison of current vegetation, we considered site S11 Plot 3 (the lowest of our plots on Cox Island) to be the best reference area for site S59; these results are shown in Table 11. High marsh and tidal swamp data are presented separately (Tables 12 and 13). “Relative percent cover” of native species and introduced species represents the proportion of all cover of living plants that was native or introduced. Species names and native/nonnative status are generally from the USDA PLANTS website (<http://plants.usda.gov>), but locally favored nomenclature was given precedence.

Table 11. Summary of plant community composition at study sites in 2006: Low marsh.

Blanks represent zero values; cover can total more than 100% due to overlapping vegetation. Student's t-tests were used to compare cover for species with >5% cover in any plot; values that differed significantly between the restoration site (S59) and reference site are in **bold type** and are marked with an asterisk(*). Introduced species are shaded. Color shading: blue = reference site; yellow = restoration site.

Low Marsh		Average percent cover			
Common name	Scientific name	S11 P3	S59 P1	S59 P2	S59 P3
creeping bentgrass	<i>Agrostis stolonifera</i>	0.1	3.4*	1.0	34.8*
Pacific silverweed	<i>Argentina egedii</i>		0.3	0.9	0.3
saltbush	<i>Atriplex patula</i>		0.1		
pond water-starwort	<i>Callitriche stagnalis</i>		1.4	0.6	3.8
Lyngbye's sedge	<i>Carex lyngbyei</i>	16.6	77.6*	87.6*	0.4
slough sedge	<i>Carex obnupta</i>			0.1	1.0
brass buttons	<i>Cotula coronopifolia</i>			0.1	0.4
tufted hairgrass	<i>Deschampsia caespitosa</i>	24.8		0.8*	8.8*
seashore saltgrass	<i>Distichlis spicata</i>	28.1			
creeping spikerush	<i>Eleocharis palustris</i>	0.1	8.9*	4.0	17.8*
dwarf spikerush	<i>Eleocharis parvula</i>	4.6		0.9	5.5
small bedstraw	<i>Galium trifidum</i>		0.1*		
Baltic rush	<i>Juncus balticus</i>	0.6	0.8	0.2	
lilaeopsis	<i>Lilaeopsis occidentalis</i>	17.5		0.6*	22.5
awl-leaf lilaea	<i>Lilaea scilloides</i>				0.1
water mudwort	<i>Limosella aquatica</i>			0.1	
reed canarygrass	<i>Phalaris arundinacea</i>			0.3	
clustered dock	<i>Rumex conglomeratus</i>		0.1		0.1
dock	<i>Rumex</i> sp. (not <i>R. occidentalis</i>)		0.1		
widgeongrass	<i>Ruppia maritima</i>				1.3
softstem bulrush	<i>Schoenoplectus tabernaemontanii</i>	3.4	13.6		0.1
seacoast bulrush	<i>Schoenoplectus maritimus</i>	0.4			
seaside arrowgrass	<i>Triglochin maritimum</i>	29.4			
common cattail	<i>Typha latifolia</i>		0.3		
	Channel				2.5
	Mud	1.0	2.0	1.8	7.4
	Woody debris				0.1
	% NATIVE	100.0	95.4	98.1	59.8
	% INTRODUCED	0.0	4.6	1.9	40.2

* significantly different from reference site at p<0.05 using Student's t-test

Table 12. Summary of plant community composition at study sites in 2006: High marsh. Zero values are not shown; cover can total more than 100% due to overlapping vegetation. Introduced species are shaded. Color shading: blue = reference site.

High Marsh	Common name	Scientific name	Percent cover	
			S11 P1	S11 P2
	creeping bentgrass	<i>Agrostis stolonifera</i>		0.1
	Pacific silverweed	<i>Argentina egedii</i>	0.1	49.8
	saltbush	<i>Atriplex patula</i>	1.5	
	Lyngbye's sedge	<i>Carex lyngbyei</i>	0.2	10.0
	tufted hairgrass	<i>Deschampsia caespitosa</i>		0.4
	seashore saltgrass	<i>Distichlis spicata</i>	27.9	10.1
	hairy willow-herb	<i>Epilobium ciliatum</i>	0.6	
	coast toothed fireweed	<i>Erechtites minima</i>	0.1	
	common bedstraw	<i>Galium aparine</i>	1.0	1.5
	meadow barley	<i>Hordeum brachyantherum</i>		0.5
	Baltic rush	<i>Juncus balticus</i>	77.9	58.3
	clustered dock	<i>Rumex conglomeratus</i>	0.1	
	curly dock	<i>Rumex crispus</i>	0.6	0.1
	western dock	<i>Rumex occidentalis</i>		0.3
	tall fescue	<i>Schedonorus phoenix</i> *		0.1
	Henderson's checkerbloom	<i>Sidalcea hendersonii</i>		0.1
	sowthistle	<i>Sonchus</i> sp.	0.1	
		Litter	7.5	3.8
		Woody debris	1.0	
		relative % native	92.1	97.0
		relative % introduced	0.7	0.2

*former name: *Festuca arundinacea*

Table 13. Summary of plant community composition at tidal swamp sites (scrub-shrub and forested tidal wetlands) in 2006. Zero values are not shown. Student's t-tests were used to compare cover; values that differed significantly between the restoration site (S65) and paired reference plot (S63 P2) are in **bold type** and are marked with an asterisk(*). Introduced species are shaded. Color shading: yellow = restoration site; green = reference sites.

Scrub-Shrub/Forested	Common name	Scientific name	Percent cover in 2006†						
			S63 P1	S63 P2	S65 P1	S65 P2	S65 P3	S65 P4†	Y28 P5
	yarrow	<i>Achillea millefolium</i>	0.1						2.1
	creeping bentgrass	<i>Agrostis stolonifera</i>				0.1			3.1
	sea-watch angelica	<i>Angelica lucida</i>							1.1
	Pacific silverweed	<i>Argentina egedii</i>		2.4	0.1				18.9
	Douglas' aster	<i>Symphytotrichum subspicatum</i>	0.3	0.9			0.1		4.8
	Pacific lady-fern	<i>Athyrium filix-femina</i>	14.2	2.5	1.8	3.0	15.4	1.1	1.3
	saltbush	<i>Atriplex patula</i>							0.5
	Pacific reedgrass	<i>Calamagrostis nutkaensis</i>		0.1					0.1
	slough sedge	<i>Carex obnupta</i>	32.0	31.0	2.3*	0.3*		0.1*	5.4
	western water hemlock	<i>Cicuta douglasii</i>				0.3			
	bull thistle	<i>Cirsium vulgare</i>							0.1
	giant horsetail	<i>Equisetum telmateia</i>							0.1
	coast toothed fireweed	<i>Erechtites minima</i>	0.1						
	common bedstraw	<i>Galium aparine</i>		0.1	0.2	0.5	1.9		0.4
	small bedstraw	<i>Galium trifidum</i>	0.3	0.3					0.1
	salal	<i>Gaultheria shallon</i>	0.1	0.3					
	cow parsnip	<i>Heracleum maximum</i>		1.1				2.6	0.9
	common velvetgrass	<i>Holcus lanatus</i>							0.1
	Baltic rush	<i>Juncus balticus</i>							3.4
	soft rush	<i>Juncus effusus</i>	0.1						6.3
	marsh pea	<i>Lathyrus palustris</i>							0.2
	black twinberry	<i>Lonicera involucrata</i>	5.8	29.3					23.3
	birdsfoot trefoil	<i>Lotus corniculatus</i>				0.1	0.1		
	skunk cabbage	<i>Lysichiton americanus</i>	22.7				0.6		
	false lily-of-the-valley	<i>Maianthemum dilatatum</i>							0.1
	Pacific crabapple	<i>Malus fusca</i>	2.5	1.7		0.1			2.9
	coastal manroot	<i>Marah oreganus</i>						0.1	
	water parsley	<i>Oenanthe sarmentosa</i>	6.6	10.5		12.9	0.1*		3.8
	reed canarygrass	<i>Phalaris arundinacea</i>	1.4	1.8	92.8*	44.0*	85.5*	97.7*	27.1
	Sitka spruce	<i>Picea sitchensis</i>	1.3	37.3					
	creeping buttercup	<i>Ranunculus repens</i>				1.1	1.1		
	Himalayan blackberry	<i>Rubus armeniacus</i>	0.4	1.1				0.1	
	spreading gooseberry	<i>Ribes divaricatum</i>	0.2						
	cutleaf blackberry	<i>Rubus laciniatus</i>			11.5	11.3	0.8	0.8	
	salmonberry	<i>Rubus spectabilis</i>	1.2			1.4			
	trailing blackberry	<i>Rubus ursinus</i>	0.8	3.8					3.5
	clustered dock	<i>Rumex conglomeratus</i>							0.1
	curly dock	<i>Rumex crispus</i>							0.1
	western dock	<i>Rumex occidentalis</i>		0.1					0.1
	Hooker willow	<i>Salix hookeriana</i>	45.0			65.8	1.5		

Scrub-Shrub/Forested	Common name	Scientific name	Percent cover in 2006†					
			S63 P1	S63 P2	S65 P1	S65 P2	S65 P3	S65 P4†
	small-fruited bulrush	<i>Scirpus microcarpus</i>				1.0	3.4	
	Douglas' spiraea	<i>Spiraea douglasii</i>	0.1	0.8				
	starwort	<i>Stellaria sp.</i>				0.1	0.1	0.1
	common cattail	<i>Typha latifolia</i>	1.4					
	stinging nettle	<i>Urtica dioica</i>					0.3	0.2
	evergreen huckleberry	<i>Vaccinium ovatum</i>		3.5				
	American brooklime	<i>Veronica americana</i>	0.1			0.1		
	giant vetch	<i>Vicia nigricans ssp. gigantea</i>	0.7	0.8	2.5	3.9	14.5	2.5*
	Channel			1.7				
	Litter				0.1			1.5
		relative % native	98.6	97.8	6.1	61.2	30.2	6.2
		relative % introduced	1.4	2.2	93.9	38.8	69.8	93.8

† For site S65 Plot 4, baseline data were obtained in 2007 under a related project (Brophy 2007b, 2008).

Figure 6 illustrates species richness within study plots.

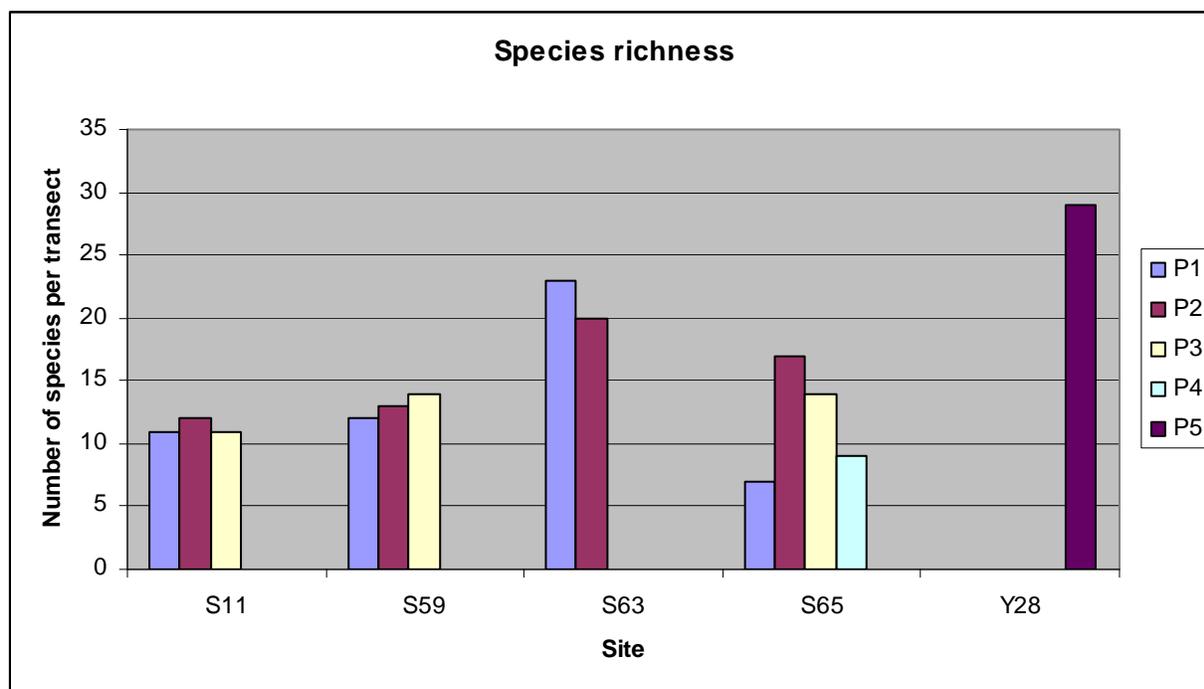


Figure 6. Species richness for study plots.

Tables 14 and 15 show similarity indices comparing restoration and reference sites. A related project (Brophy 2007b, 2008) allowed us to determine the change in similarity after restoration at site S65 (Table 15).

Table 14. Similarity index for S59 plots compared to Cox Island (S11) Plot 3

S11 P3 vs:	Weighted % similarity	Unweighted % similarity
S59 P1	28.02	43.48
S59 P2	37.69	58.33
S59 P3	49.03	56.00

Table 15. Similarity index in 2006 and 2008 for S65 restoration site compared to S63 reference site Plot 2.

S63 P2 vs:	Weighted % similarity		Unweighted % similarity	
	2006	2008	2006	2008
S65 P1	11.72	7.93	44.44	32.43
S65 P2	16.50	19.50	37.84	48.48
S65 P3	8.24	16.38	35.29	40.00
S65 P4	9.64	11.38	41.38	34.29

Figure 7 illustrates post-restoration changes in vegetation at site S65. These data were collected and analyzed in a related project (Brophy 2007b, 2008).

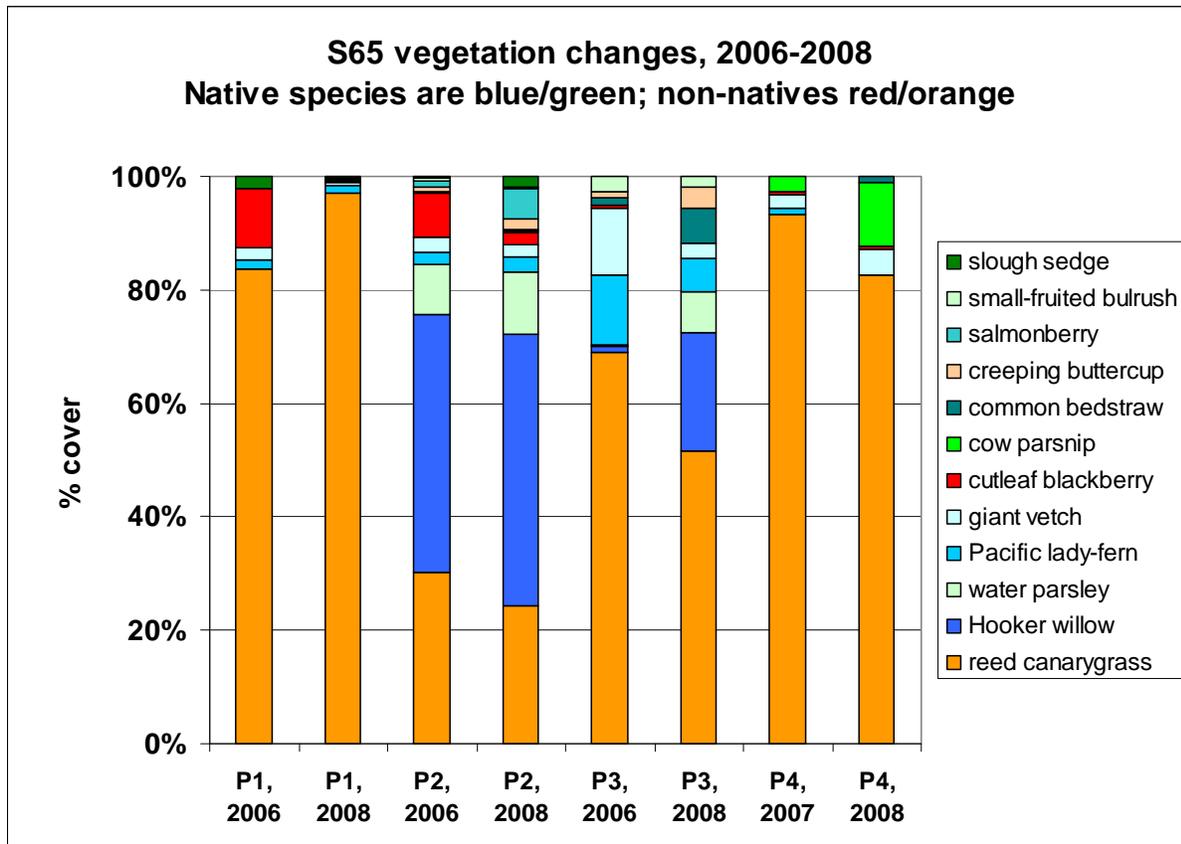


Figure 7. Results from related project (Brophy 2007b, 2008): Tidal Swamp Restoration Site S65 plant community composition in sample plots, 2006-2007 (pre-restoration) vs. 2008 (post-restoration Year 1). All species over 2% cover are shown. Native species are symbolized with blue to green; non-native species are orange to red.

Figures 8 and 9 illustrate the post-restoration change in similarity index at site S65.

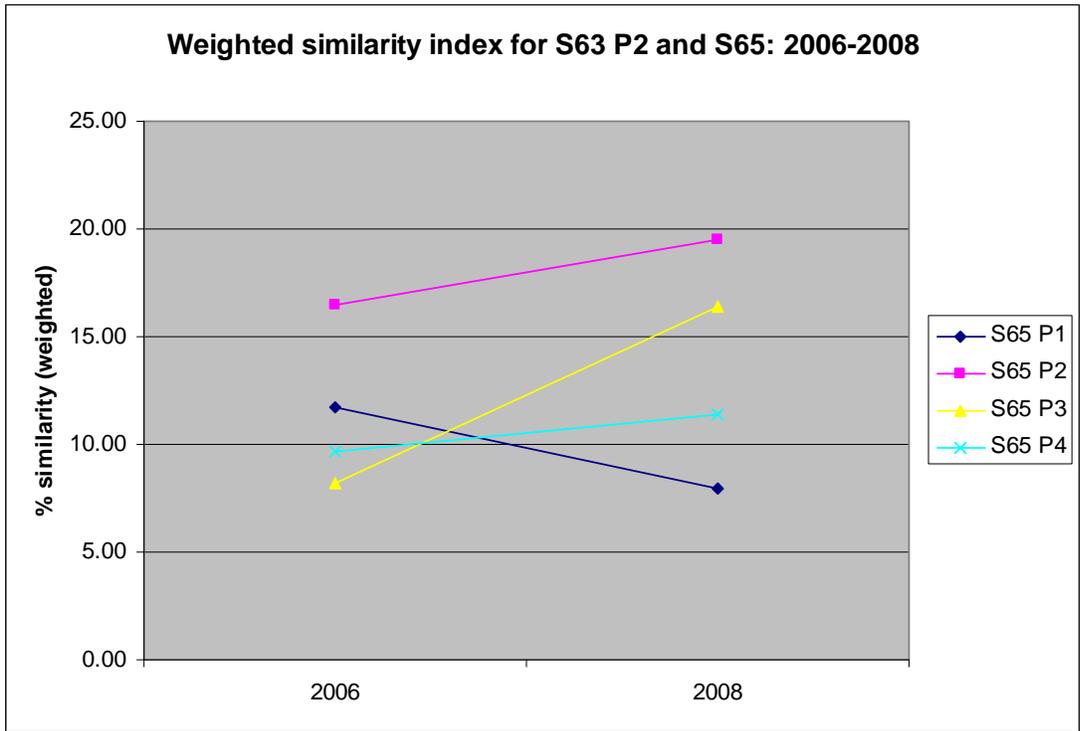


Figure 8. Weighted similarity index in 2006 and 2008 for site S65 vs. site S63 Plot 2. Decrease in similarity for P1 is due to weedy species growing in disturbed soil along excavated pilot channel.

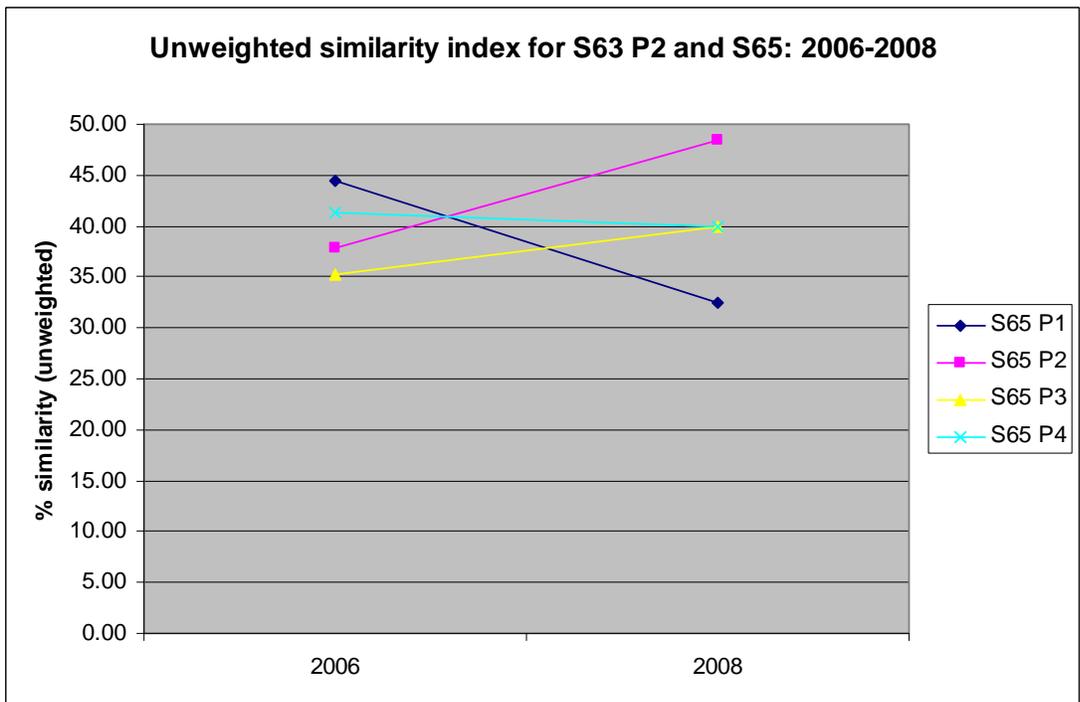


Figure 9. Unweighted similarity index in 2006 and 2008 for site S65 vs. site S63 Plot 2. Decrease in similarity for P1 is due to weedy species growing in disturbed soil along excavated pilot channel.

Figures 10 and 11 illustrate post-restoration changes in percent cover of dominant and subordinate species at site S65.

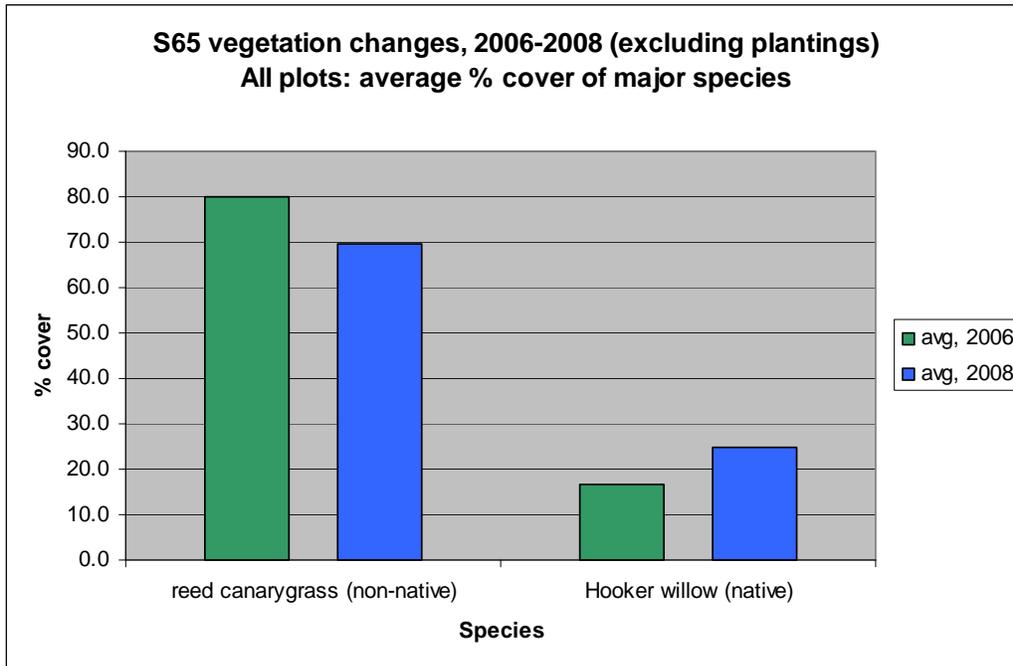


Figure 10. Tidal swamp restoration site S65: Changes in cover for major dominant species, 2006-2008. Data are averaged across all plots.

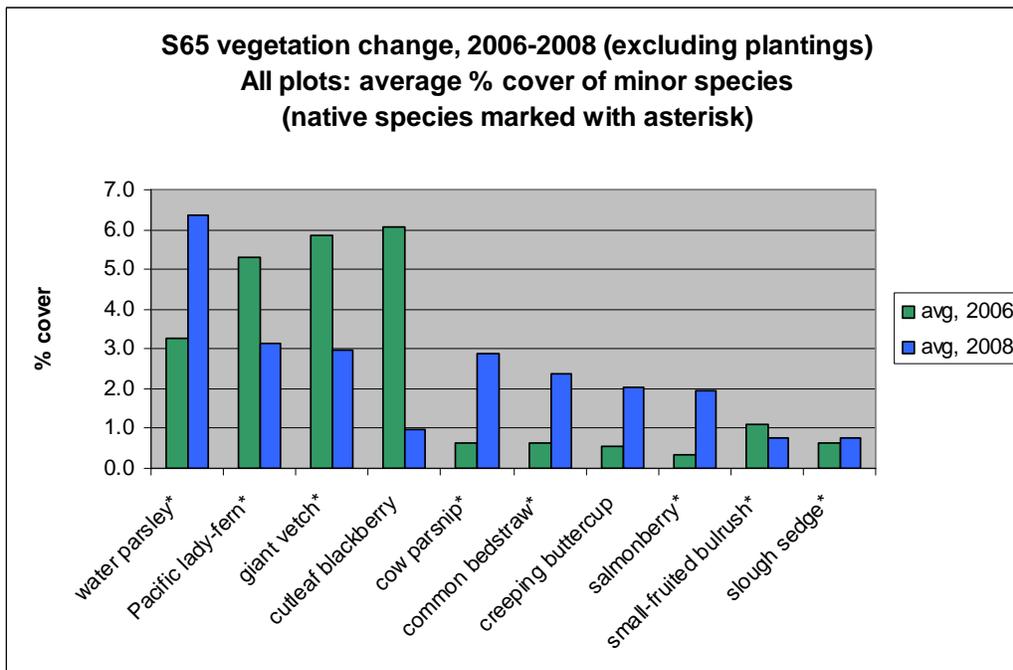


Figure 11. Tidal swamp restoration site S65: Changes in cover for minor species, 2006-2008. Data are averaged across all plots.

Woody species stem density and basal area

Stem density was calculated for woody species within each study plot with woody vegetation (Table 16).

Table 16. Woody stem densities (stems/A) at tidal swamp restoration and reference sites.

Shading: yellow = restoration site; green = tidal swamp reference sites.

Site	Black twinberry	Pacific crabapple	Hooker willow	Douglas' spiraea	Sitka spruce	Evergreen huckleberry	Salal	All trees and shrubs
S65 P2*	0	0	968	0	0	0	0	968
S63 P1	1,742	65	5,679	65	0	0	0	7,551
S63 P2	6,550	290	0	355	129	1,484	65	8,873
Y28**	6,147	97	0	0	0	0	0	6,244

* S65 Plot 2 was the only plot with woody vegetation prior to restoration.

** Yaquina site has spruce mainly along tidal channels; the study plot is scrub-shrub wetland.

We determined basal area for the single study plot that had trees (site S63 Plot 2). The only tree species present was Sitka spruce (*Picea sitchensis*); basal area was 53 sq ft/A (12 sq m/ha).

Landscape setting

Landscape metrics for study sites are shown in Table 17.

Table 17. Landscape setting data for study sites. Shading: blue = tidal marsh reference site; yellow = restoration sites; green = tidal swamp reference sites.

Site	Habitat class interspersion	# of habitat classes	Habitat classes present	Slope (%)	Aspect	Geomorphic setting
S11	high	2*	water/mud, emergent	0.2	SW	bay fringe island
S59	high	2	water/mud, emergent	0.03	S	channel fringe shore
S63	high	4	water/mud, emergent, scrub-shrub, forested	0.3	E	channel fringe shore
S65	medium	4	water/mud, emergent, scrub-shrub, forested	0.2	W	channel fringe shore
Y28	high	4	water/mud, emergent, scrub-shrub, forested	0.04	W	channel fringe shore

Discussion

Major findings are marked in **bold** in this section.

Elevation and subsidence

Tidal swamp reference sites (S63 and Y28) and restoration site S65 had wetland surface elevations near MHHW (0.26 ft below MHHW to 0.7 ft above MHHW) (Table 6). The similarity of the elevations supports the suitability of the reference sites, and suggests that tidal swamp restoration is likely to succeed at S65. Even the highest parts of site S65 (e.g., Plot 4) will be inundated monthly, except for 1 month in late summer (Appendix 2, Figures A4 and A9).

By contrast, restoration site S59 has subsided substantially; its soil surface is much lower in the local tide range, averaging 2 to 2.5 ft below MHHW. Although it was once a tidal swamp, this site is now low tidal marsh because of its low elevation (Appendix 4, Photo A15). Site S59's low elevation is probably due to subsidence, a common phenomenon in Oregon diked tidal wetlands (Frenkel and Morlan 1991). Site S59 was mapped as tidal swamp in the 1850's (Appendix 1, Map 3), so it probably had a surface elevation similar to site S63 (about 1/2 mile north) prior to its conversion to agricultural use. If so, the site has undergone 2-3 ft of subsidence, similar to the amount of subsidence measured at other diked tidal wetlands in Oregon (Brophy 2004, Cornu and Sadro 2002) and 2-3 times greater than that described in the Salmon River estuary by Frenkel and Morlan (1991). Sites with very high soil organic matter content may be particularly vulnerable to subsidence. Both Sites S59 and S63 have highly organic soils (histosols); at the few Oregon tidal swamps that have been studied to date, such high organic levels appear to be typical (Diefenderfer 2007; Elliot 2008; Brophy 2008, 2009, in preparation).

The initial dike breach at site S59 occurred over 10 years ago. In the Salmon River estuary, Frenkel and Morlan (1991) estimated it would take over 50 years of sediment accretion for a diked marsh that had subsided 35cm to return to high marsh elevation. Without sediment accretion measurements at S59, we cannot easily determine the site's potential to restore to tidal swamp, but it seems very likely that the process will be lengthy.

Interestingly, the second restoration site (S65) does not show evidence of subsidence.

Elevations on the majority of the site are very similar to the reference sites, despite diking and grazing. These results suggest that tidal swamp restoration has a high likelihood of success here, since the tidal inundation regime will be similar to that of the reference sites and soil conditions are favorable for native plant growth.

Site S65 may originally have been even higher than the reference sites, or its soils may have been less vulnerable to subsidence due to soil chemistry or other factors. Its position in the freshwater tidal zone and its geomorphic setting inside a sharp bend of the river probably create a more active alluvial deposition environment compared to the reference sites. Alluvial material deposited during river floods is probably less vulnerable to subsidence compared to the highly organic soils of less energetic sites like site S63.

Cox Island (reference site S11) has a wide range of elevations (and resulting tidal inundation regimes). Plot 3 is about a foot below MHHW; its vegetation is a mix of low and high marsh species. Plots 1 and 2 are 1.5 ft higher, only slightly lower than the tidal swamp reference sites. We expected to see these high elevations at Cox Island Plots 1 and 2 and the island's natural levee, since the east and north sides of Cox Island were Sitka spruce swamp in the 1850's (Appendix 1, Map 3; Hawes *et al.* 2002). We recommend considering woody plantings to restore Sitka spruce and other native tidal swamp species in this area. Further investigation of salinity (both surface water and soil salinity) will be needed to select specific locations. Given the presence of invasive saltmeadow cordgrass (*Spartina patens*) on the site, planting methods should avoid excessive soil disturbance.

Tidal vs. geodetic datums

Although the geodetic elevations of the two tidal swamp reference sites (S63 and Y28) are 1-2 ft apart, their elevations relative to MHHW are similar. This illustrates the importance of using a consistent tidal datum in characterizing tidal wetlands and predicting restoration results: ecosystems respond to tidal inundation, not to geodetic datums. MHHW may be a more useful datum than MLLW for characterizing high marsh and tidal swamp, since these wetland surfaces are found near MHHW.

Hydrology

Tidal inundation regime

We found that tidal inundation regimes differed sharply between sites, due to their different elevations. The lowest restoration site, S59, inundates every day year-round (Appendix 2, Figure A2). Using the more traditional "percent inundation" metric, this site is inundated 40 to 50% of the time in winter months, and 25 to 30% in summer (Appendix 2, Figure A7). This is in sharp contrast to its likely condition prior to diking, illustrated by reference site S63 just a half-mile upstream.

Tidal swamps (S63, Y28) had a highly seasonal tidal inundation regime; tidal inundation of the wetland surface continues throughout the summer on the highest tide cycles (spring tides). Winter inundation is at least twice as frequent as summer inundation (Appendix 2, Figures A3, A8). The same seasonal pattern is seen at the Yaquina tidal swamp reference site (Y28) (Appendix 2, Figures A5, A10), but inundation is even less frequent there, since the site is at a higher elevation.

The elevation at restoration site S59 is so low that it inundates much more often than the low marsh at Cox Island (Appendix 2, Figures A1, A2, A6, and A7). Clearly, subsidence has strongly affected the ecosystem at site S59 and changed the suite of wetland functions it provides, compared to its historic condition. For further discussion, see "Site S59 conditions and wetland functions" below.

Prior to restoration, the dike at site S65 prevented nearly all tidal inundation, but restoration returned inundation to natural levels. With the dike intact, tidal inundation occurred only 6 days per year (Appendix 2, Figure A11) at typical (median) river flow levels. After restoration, tidal inundation is expected to occur on 119 days each year at typical river flow levels (Appendix 2, Figure A11). The restored, natural tidal inundation regime inundates the site even during the driest months of the summer on full and new moon tide cycles (Appendix 2, Figures A4, A9, A13, A15). Post-restoration monitoring using tide gauges installed on Sites S65 and S63 confirmed that the reference and restoration sites have matching tidal inundation regimes (Brophy 2008).

Based on our inundation models, river flows have a strong influence on inundation regimes in the tidal swamps (Appendix 2, Figures A12-A15). Median river flows (50th percentile) increase inundation frequency by about 25% during winter months compared to inundation modeled using tide level data only. High river flows (95th percentile) can triple inundation frequency during wintertime, particularly for sites in the middle and higher swamp elevations like S63 P2 and S65 P4 (at 0.5 and 1.5 ft above MHHW respectively). High river flows can raise inundation frequency by 25 to 50% even during spring and fall. These fluvial effects should be considered when planning restoration, since they can affect plant community development.

Water table depth

Our observations suggest that tidally-influenced water table fluctuation in tidal swamps may be a little-understood controlling factor in tidal swamp ecology. Prior to this study, no literature existed on seasonal patterns of groundwater level in Oregon tidal swamps. We measured water table depth weekly during March through June 2007 at the Siuslaw tidal swamp reference and restoration sites (S63 and S65). This is the spring drawdown period, when seasonal wetlands typically show a falling water table. (As described in the QAPP, we did not observe water table depth at the tidal marsh sites.)

We observed a typical seasonal wetland pattern at the tidal swamp restoration site (S65); water tables here dropped below wetland levels by late May (Figure 1). Wetlands usually have water tables within a foot of the soil surface (Environmental Laboratory 1987), so these findings show that the tidal swamp restoration site (S65) had been effectively dewatered by the dike and restrictive culvert. Groundwater at site S65 also showed some response to tidal cycles (Figure 3) even before restoration, particularly in the groundwater well near the site's main ditch, which had muted tidal flow (P2). However, the site's dike had apparently converted the site from a year-round wetland with daily water table fluctuation to a seasonal wetland that dried out during the summer.

By contrast, water tables at tidal swamp reference sites S63 and Y28 were very stable and generally stayed at wetland levels throughout the summer. The water table in the Sitka spruce swamp plot (P2) at site S63 showed surprising stability between high tide events, hovering around 12in below the soil surface (Figure 2). A brief investigation of the soil profile showed hydric indicators (including bright redox concentrations) above 12in depth, with a distinct horizon boundary at about 12in, but detailed profile characterization was not conducted.

Groundwater level in the willow swamp (P1) at S63 was consistently about a foot higher compared to spruce swamp (Figure 2). Hydric soil indicators from 0-30" at P1 suggested the soil there is constantly saturated. This may have been partly due to the lower elevation at P1, but hillslope seepage, channel network density, and beaver activity probably also play a role in maintaining the willow swamp's higher water table. Only at Site Y28 in late summer did groundwater drop more than a foot below the soil surface, and even then, monthly high tides (spring tides) rapidly "reset" groundwater to a level near the soil surface (Figure 5).

A study of water table levels at nontidal wetland reference and restoration sites in the South Slough National Estuarine Research Reserve (Brophy 2005b) also showed more stable water levels at the reference site. The water table at the least-disturbed site (Tom's Creek) held steady within a few inches of the soil surface throughout the entire summer, whereas the restoration sites (Anderson and Wasson Creeks) showed much more variability and seasonal drying.

Groundwater levels at the tidal swamp reference sites (S63 and Y28) were highly responsive to tidal cycles, even when the wetland surface was not inundated (Figures 2, 4, and 5). Automated water level logger data showed that the highest groundwater peaks occurred during the extreme tide cycles (new and full moon), when the wetland surface was inundated. (Groundwater wells were overtopped during these events, as shown by the sharp rise in water level on the highest tides.) At S63 P2 and Y28 P5, groundwater also fluctuated in response to tidal cycles during neap tide cycles, even when the wetland surface was not inundated. Groundwater response to neap tidal cycles illustrates the high hydraulic conductivity of soils at these sites, particularly since the groundwater wells were located more than 20 ft from the nearest tidal channel. The high hydraulic conductivity of these tidal swamp soils may be due to their high organic matter content; peaty soils are often very hydraulically conductive (Mitsch and Gosselink, 1993). Wetlands with strong, regular fluctuation in water level are among the most productive and the most likely to export biota, nutrients and energy to other nearby ecosystems (Mitsch and Gosselink, 1993).

Surface water salinity

Salinity at Cox Island (reference site S11) was typical of lower estuary brackish marsh, averaging 19-20 ppt (mesohaline) in summer and around 3-5 ppt (oligohaline) in winter. This large seasonal salinity variation is typical of brackish marsh in Oregon, and illustrates the fact that salinity is better characterized as a "salinity regime" rather than a single salinity designation such as "mesohaline."

Salinities at the tidal swamp reference sites (S63 and Y28) were less saline, yet still strongly brackish. This is in contrast to literature from the Columbia River estuary, where Sitka spruce tidal swamps have been described as occurring in the freshwater tidal zone (Fox *et al.* 1984). Brackish surface water salinities were observed in winter as well as summer, though winter salinities were lower. Tidal swamps with the highest (mesohaline) summer salinities (5-20ppt) were dominated by Sitka spruce and black twinberry, with an herbaceous layer that varied by site. The tidal swamp with oligohaline summer salinity (<5ppt) (site S63 P1) was dominated by

Hooker willow, slough sedge and skunk cabbage – species typical of nontidal freshwater wetlands on the Oregon coast.

Soils

Organic content of soils was generally high, particularly at the tidal swamp sites. Two of three tidal swamp plots had soils classified as histosols according to standard methods (Soil Survey Staff 1992), as did the lower marsh plot at Cox Island (S11 P3). Soils at the tidal swamp restoration site (S65) were not classified as histosols, but still had unusually high organic content for pasture soils (11 to 14% OM). Interestingly, despite its grazing history, restoration site S59 had very high soil organic matter content; two of three plots at site S59 had soils classified as histosols. The high organic content of the soil at S59 suggests that despite its past alterations, the site may have good potential to provide wetland functions that are dependent on biological activity in the soil, such as water purification and invertebrate habitat (Adamus 2005). The reference sites, which show even higher levels of soil organic content, may provide such functions at even higher levels.

Soil textures at the study sites were generally clay loam to loam, and pH was acidic. These characteristics are typical of most west coast tidal wetlands (Zedler 2001, Mitsch and Gosselink 1993).

Soil salinity was significantly correlated to surface water salinity (Figure 12; $R^2=0.76$, $p<0.01$); soil salinity averaged 20% higher than surface water salinity. Site S65 had the lowest soil salinities, due to its location in the freshwater tidal zone.

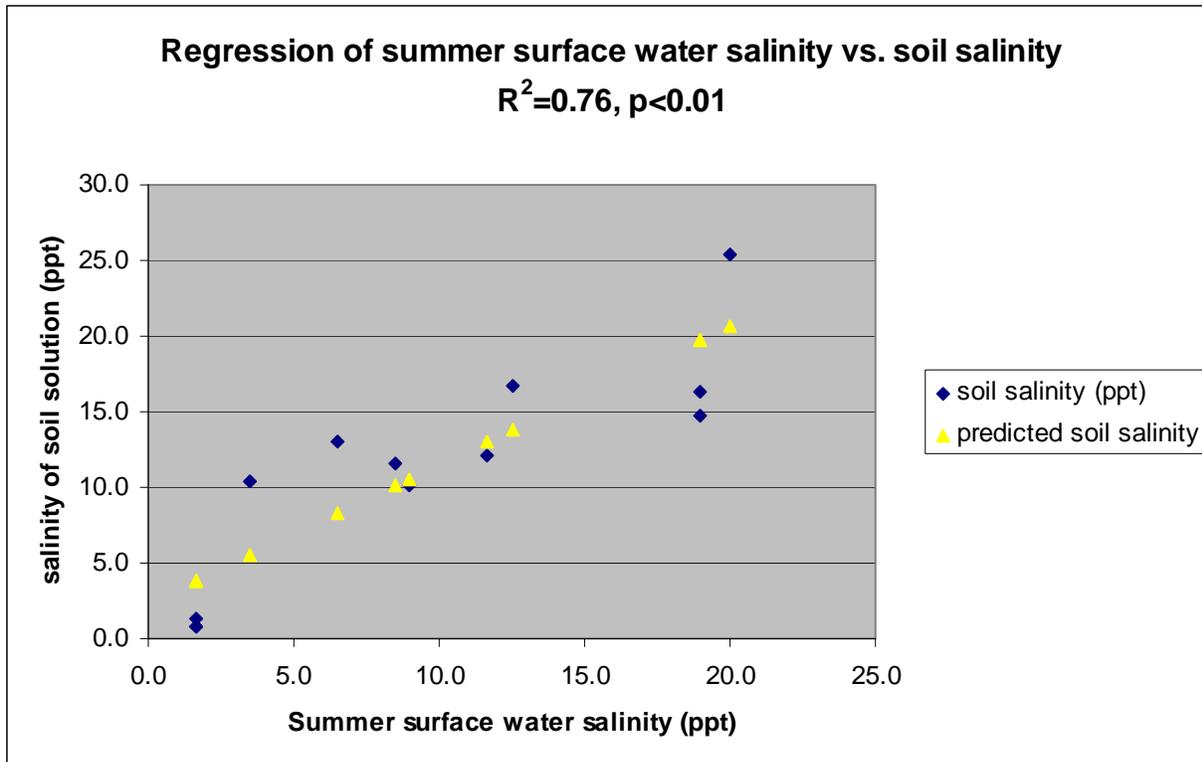


Figure 12. Soil salinity vs. summer surface water salinity vs. at Siuslaw and Yaquina study sites.

Vegetation

Vegetation mapping

The relatively high proportion of mud flat at site S59 (about half of the site) was not unexpected, given the site’s subsidence. The site’s elevation (4.8 to 5.3 ft NAVD88, 2 to 2.5 ft below MHHW) was over a foot lower than the low marsh monitored at Cox Island (reference site S11). Despite the low elevation, native brackish marsh species are thriving at the site. Lyngbye’s sedge has formed large monospecific stands in the lower parts of the site; this species often dominates in recovering brackish marsh in Oregon (Brophy 2007c, Frenkel and Morlan 1991).

Reed canarygrass occupied a large part of site S65 prior to restoration, but extensive woody plantings have been successfully established as part of site restoration (Brophy 2008). The map of vegetation types (Appendix 1, Map 11) can be used to track future development of woody vegetation at the site.

For both restoration sites, we recommend the vegetation maps be revised using updated aerial orthophotos to quantify large-scale site changes (see “Future monitoring recommendations” below).

Plant community composition: Restoration-reference site comparisons

Plant communities differed significantly between the restoration sites (S59 and S65) and their respective reference sites, Cox Island (S11) and S63. Species richness was similar between restoration and reference sites (Figure 6), but similarity between restoration and reference sites was low (Tables 14 and 15). Since the weighted similarity index is the more sensitive indicator of similarity between plant communities, we focus on that measure in the following discussion.

Restoration site S59

Weighted similarity between restoration site S59 and the low marsh reference plot at Cox Island (S11 P3) was 30 to 50%. This is a fairly low degree of similarity, considering the site's first major dike breach occurred about 10 years prior to this study. Thom *et al.* (2002) reported similarity indices around 30-50% four to five years after dike breaching at the Elk River tidal marsh restoration site in Grays Harbor, Washington, and similarities of 60-80% after 10 years. Like our site, the Elk River site was subsided 0.5 to 1m; Thom *et al.* calculated similarity of the subsided restoration site to the adjacent unsubsided high marsh reference site, 0.5 to 1m higher in elevation. By contrast, we restricted the comparison to that portion of the Cox Island reference site that was at a similar elevation to the restoration site (S11 P3). This stratified analysis method would tend to produce higher similarity indices compared to the methods used by Thom *et al.* A similarity index comparing site S59 to the tidal swamp reference sites approximating its pre-diking condition (S63, Y28) would have showed much lower similarity. Although further study would help clarify these relationships, it is clear that the speed of recovery of plant communities varies greatly from site to site.

A positive indicator of future plant community development at site S59 is the fact that nearly all of the dominant and subdominant species at the reference site are already present at the restoration site. The exceptions are the two species characteristic of higher salinities: seashore saltgrass (*Distichlis spicata*) and seaside arrowgrass (*Triglochin maritimum*). Surface water and soil salinities at site S59 are lower than at the reference site (Tables 9 and 10), explaining the absence of these halophytes.

Restoration site S65

Similarity between restoration site S65 and the nearby reference site (S63) was very low in 2006, but woody plantings have established well and similarity is expected to increase as plantings grow. The low initial similarity was not surprising; most of the restoration site was heavily dominated by reed canarygrass, while the reference site has a diverse mix of trees, shrubs, and herbaceous species. As described above, the North Fork Siuslaw River Bridge mitigation project allowed us to repeat the vegetation monitoring in 2008 and recalculate similarity indices; results are discussed in "Post-restoration trends in plant community composition at site S65" below.

Woody species density and basal area

Both restoration sites were originally tidal swamps with cover dominated by woody species, but trees and shrubs were removed to allow agricultural use of the sites. At the time of this study, neither restoration site had much woody cover. Site S59 had no trees or shrubs; only one plot (P2) at site S65 was dominated by woody plants, with high cover (66%) of Hooker willow (*Salix hookeriana*). This species was not present within the reference plot that was most similar in elevation (S63 P2), so we compared cover and stem density for this species between S65 P2 and S63 P1, which was at a slightly lower elevation. Hooker willow cover was higher at the restoration site ($p < 0.05$; Table 13) but stem density was much higher at the reference site ($p < 0.05$; Table 16).

Tidal swamp plant communities

We used the vegetation data from Sites S63 and Y28 to create new plant community descriptions for estuarine intertidal scrub-shrub and estuarine intertidal forested habitat classes, published in Christy and Brophy (2007). No quantitative data have previously been published on plant community composition of Oregon's brackish tidal swamps, and these communities are not present in Oregon's plant community classification system (Kagan *et al.* 2005). Our new plant community descriptions will be included in the next edition of the classification.

Similar brackish tidal swamp communities in the Nehalem River estuary were characterized in a related study (Brophy *et al.* 2008, 2009; Brophy *et al.*, in preparation). Dominant woody vegetation in the Nehalem brackish tidal swamp was similar to that at site S63 P2 and Site Y28 P5, including Sitka spruce (*Picea sitchensis*), black twinberry (*Lonicera involucrata*), and Pacific crabapple (*Malus fusca*). Nonwetland species such as salal (*Gaultheria shallon*) and huckleberry (*Vaccinium* spp.) were fairly abundant, but were consistently growing on the abundant fallen logs or on spruce root platforms that were elevated well above the hydric soil surface (see "Beaver and Sitka spruce as system engineers?" below).

Post-restoration trends in plant community composition at site S65

A related project allowed us to conduct post-restoration vegetation monitoring at site S65. Detailed results are provided in Brophy (2008). Briefly, we observed four trends in plant community composition following restoration of site S65:

1) Increased plant species diversity. In three of four plots (all but Plot 1), vegetation cover was distributed more evenly among species in 2008 compared to 2006 (Figure 7). Dominance by reed canarygrass decreased significantly (see below), and cover of desirable native species increased (though the differences were not generally significant).

3) Decreased cover of reed canarygrass. Although it remains dominant in all plots, reed canarygrass declined significantly ($p < 0.05$) from 80% to 70% cover when averaged across all

four plots (Figure 10). In our plans for this site, we suspected that good control of reed canarygrass would only be possible through shading by woody plantings. However, Year 1 results suggest that competition from other herbaceous species may assist in suppression of reed canarygrass.

Plot 1 showed a slight increase in reed canarygrass cover, due to decreased cover by the upland invasive cutleaf blackberry (see #3 below). In Plot 2, willow is expanding and native herbaceous wetland species are increasing at the expense of reed canarygrass.

3) Decrease in cover of non-native, invasive blackberries. In upland pastures, cessation of grazing without active vegetation management often leads to problems with non-native Himalayan and cutleaf blackberries. However, despite the removal of livestock from this site a few years ago, plots 1 and 2 both show noticeably lower cover of blackberry in 2008 compared to 2006 (Figures 7 and 11). The change – from an average of 6.6% cover in 2006 to less than 1% in 2008 – is significant at $p < 0.05$ using the Student's *t* statistic. Decreased blackberry cover may be due to increased soil saturation associated with the dike breach and the return of tidal influence; blackberries are not adapted to hydric (saturated, anaerobic) soils. Mowing of the site in 2007 in preparation for site work may also have contributed to the decline of blackberry; future monitoring will help evaluate this trend.

4) Trend towards increased cover of native species and wetland species. Hooker willow cover increased from an average of 17% in 2006 to 25% in 2008 (Figure 10); cover of five out of 8 minor native species increased during the first year after restoration (Figure 11). Three native species showed decreased cover in 2008 compared to 2006 (Figure 11). These native species cover changes were small in magnitude and not statistically significant during the brief post-restoration period. Of the two non-natives illustrated in Figure 11, the wetland species (creeping buttercup) increased, while the upland species (cutleaf blackberry) decreased.

Landscape setting

Habitat class interspersion

Tidal channels and mud flats were considered along with emergent, scrub-shrub and forested wetland classes to determine interspersion. Since we characterized interspersion for the entire wetland associated with each study site rather than for study plots or sites *per se*, the information in Table 17 is somewhat different from the data in the vegetation tables and charts. The wetland associated with site S65, for example, consists of almost 15A of intermingled willow swamp, Sitka spruce- and alder-dominated forested wetland, and old pasture dominated by reed canarygrass. Study plots 1, 3 and 4 are located in the restoration focus area, which is the old pasture; study plot 2 is in the willow swamp.

All of the wetlands have a medium to high degree of interspersion, showing their high potential for providing wetland functions dependent on site structural complexity (Table 17). Complex tidal channel networks resulted in high interspersion values for most sites, even when vegetation patterns were simpler. The tidal swamp reference sites (S63 and Y28) have particularly high site complexity due to dense channel networks, the presence of herbaceous

openings in an otherwise woody canopy, and diverse heights of woody species from low shrubs to tall Sitka spruce.

Interspersion results are partly a function of the data source; for example, if low-resolution aerials or NWI maps were used, the sites would show less interspersion. We based our assessment of interspersion on field observations and high-resolution aerial photos, both of which are data sources that tend to maximize detection of interspersion.

Slope and aspect

All sites had very low slope (under 0.5%) (Table 17); aspect varied by site and did not appear to be related to any other site characteristics.

Geomorphic setting

Sites S59, S63, S65 and Y28 are channel fringe shore wetlands; Cox Island (site S11) is a bay fringe island wetland. Adamus *et al.* (2005) report that the channel fringe shore category contains the highest acreage of Oregon tidal marsh, followed by channel fringe pocket wetlands.

Conclusions

Controlling factors in tidal swamp development

Several results of this study were surprising. Elevations for the tidal swamp sites were lower than expected; the willow swamp plot at S63 (P1) is located below mean higher high water (MHHW), and Sitka spruce and black twinberry swamp at S63 P2 and Y28 P5 were 0.5 to 0.7 ft above MHHW. In a related study (Brophy *et al.* 2009), we found similar values for tidal elevations of other outer coast tidal swamps in Oregon: Sitka spruce tidal swamp in the Nehalem River estuary was also located 0.5ft to 0.7ft above MHHW. Interestingly, brackish high marsh in this study occurred at an elevation similar to that of tidal swamp (around 0.4ft above MHHW at site S11), and in a related study, we found that brackish high marsh in the Siletz River and Coos Bay estuaries occurred at even higher elevations, ranging from 0.6 to 0.9 ft above MHHW (Brophy 2009). These observations show that brackish marsh can (and may often) be located at a higher elevation than tidal swamp relative to tidal datums. The evidence contradicts a common misperception that tidal swamps always occur at higher elevations than tidal marsh.

Consistent with their elevations near MHHW, the tidal swamps in this study are inundated by tidal flows several days each month throughout the year, even during the driest months of summer (Appendix 2, Figures A3, A5, A8, and A10). This contradicts a common misperception that tidal swamps inundate mainly in winter. High river flows at these swamp sites can generate frequent inundation even during late spring (Appendix 2, Figures A12 and A14).

Although tidal inundation occurs year-round at these mid- to upper estuary tidal swamp sites, winter river flood events may have a strong influence over tidal channel development processes. The high elevation of the natural levee at site S65 suggests that alluvial deposition rates are high in this landscape setting. Alluvial sediment deposition in this geomorphic setting is probably event-driven; flood events may play a large role in forming the channel network in tidal swamps in the middle and upper estuary. The depositional processes associated with tidal marsh development in the lower estuary are probably much more gradual (Simenstad 1983, Zedler 2001)

Salinity is probably a major controlling factor in the ecology of the tidal swamps in this study. As described above, brackish high marsh occurs at elevations similar to or higher than tidal swamps, relative to MHHW. Clearly, elevation and tidal inundation regime are not the sole factors that control development of woody vegetation (tidal swamp) *versus* emergent marsh. The most obvious additional controlling factor is salinity. Higher surface water and soil porewater salinities in the lower estuary probably prevent establishment and persistence of trees and shrubs. Small Sitka spruce saplings are often seen growing on drift logs within tidal marsh in the marine salinity zone, but they are generally stunted and do not develop into full sized trees. Large spruce trees do develop in the marine salinity zone, but only on the highest natural levees or at the base of hillslopes, where rainfall and seepage probably dilute the tidal flows.

Still, we found that tidal swamps (including Sitka spruce swamps) can definitely develop and thrive in brackish conditions. Average summer surface water salinities at both of our tidal swamp reference sites ranged well into the mesohaline range. Salinities varied strongly by plant community: willow swamp had the lowest summer salinities (surface water 3.5 ppt, soil porewater 10 ppt), while swamps dominated by Sitka spruce and black twinberry had much higher salinities (surface water 7-13 ppt, soil porewater 13-17 ppt). By contrast, broad surveys of vegetation in the Columbia River estuary stated that Sitka spruce tidal swamps occur in the freshwater tidal zone (MacDonald 1984, Fox *et al.* 1984). Although Elliot (2008) found oligohaline salinities in surface water and soil porewater of Russian Island (Columbia River) tidal swamps, averaging 1.6 ppt in summer, she found no relationship between salinity and plant community composition in her study area. It seems likely that spruce tidal swamps were once also found in the mesohaline zone in the Columbia system, but they are now almost completely missing from the landscape. Thomas (1983) documented 96% loss of spruce tidal swamp from Youngs Bay, located in the mixing zone of the Columbia system.

Beaver and Sitka spruce as “system engineers?”

Physical characteristics like tidal inundation regime and salinity are only part of the puzzle of tidal swamp ecology. During our field work in the Siuslaw swamps and other tidal swamps of Oregon, we observed unique and complex characteristics including very high soil organic matter content, high levels of beaver activity, abundant large woody debris, and prominent Sitka spruce root platforms that create an aerobic substrate well above the hydric soil surface. It seems likely that beaver and Sitka spruce interact in the swamps as “system engineers” (Wright and Jones 2006), profoundly altering site structure. Diefenderfer and Montgomery (2008) and Diefenderfer *et al.* (2008) found that beaver had a strong influence on channel morphology and step-pool

structure in tidal swamps of a regulated river system (Columbia River estuary). Further field study – particularly longterm monitoring – is urgently needed to build our understanding of the complex ecology of these once-prominent, highly impacted ecosystems.

Significance of tidal swamp data

Although the number of sites in this study was small, the results represent the first comprehensive monitoring datasets from least-disturbed brackish (mesohaline) tidal swamp habitats of Oregon. Only recently have a few studies provided quantitative characterization of Oregon tidal swamps, and these were conducted in the freshwater tidal zone of the Columbia River estuary (Diefenderfer 2007, 2008; Elliot 2008). Thomas (1983) described willow-dominated tidal swamps of the lower Columbia River estuary, but did not provide quantitative data or measurements on these habitats.

The data collected in the present study provide a starting point for ecological understanding and restoration of Oregon’s brackish tidal swamps. Such data are urgently needed. Historic vegetation mapping (Hawes *et al.* 2002) shows extensive Sitka spruce swamps in the brackish zones of most Oregon estuaries, so brackish Sitka spruce swamps were probably once a prominent component of Oregon’s coastal landscape. Most of these swamps are now gone. Brophy (2005a) documented a 97% loss of tidal swamp from the Siuslaw River estuary between the 1850’s and the present time. Similar losses were documented in Youngs Bay on the Columbia River estuary (Thomas 1983) and probably occurred on the rest of the Oregon coast as well. Established ecological principals suggest restoration should attempt to re-establish the historic “landscape structure” of habitat types (Simenstad and Bottom, 2002). To move towards that goal, habitat classes that have been disproportionately impacted should be prioritized, and tidal swamps are among the most highly impacted of tidal wetland habitat classes in Oregon (Brophy 2007a).

Information on tidal swamp ecology is important to coastal resource conservation and restoration in Oregon. The transition zone between brackish and freshwater tidal wetlands may be particularly important to Pacific Northwest juvenile salmonids (Simenstad and Bottom, 2002). Floodplain and riverine swamps provide very high levels of ecosystem services, among the highest of all wetland types (Costanza *et al.* 1997). Despite the apparent importance and extensive loss of tidal swamps, many existing and proposed tidal wetland classification systems completely omit estuarine forested and scrub-shrub wetland classes. The data collected in this study contributed to development of new plant community descriptions for Oregon’s brackish (estuarine) scrub-shrub and forested tidal wetlands (Christy and Brophy 2007), and we are working to improve recognition of the historic importance of this wetland class. Tidal wetland restoration practitioners in Oregon have expressed strong interest in restoring tidal swamps (SSNERR 2007). We are currently disseminating the data from this study to practitioners via scientific meetings, informal communications, and the Internet. We are also applying the results to help guide tidal swamp restoration at several sites in Oregon, including site S65.

Further comprehensive studies at least-disturbed tidal swamp sites are urgently needed to build a robust reference conditions database. This study has begun to characterize controlling

factors and biology of Oregon's brackish tidal swamps, but the study's constraints limited the number of sites investigated. In a related project (Brophy *et al.* 2008, 2009, in preparation), we are piloting an online reference conditions database that includes two additional tidal swamp sites. However, a robust database suitable for planning restoration projects will require data from numerous additional tidal swamps. Since tidal swamps are now rare (and becoming rarer each year), such studies are very urgent.

Site S59: General conditions and wetland functions

This study only provided a single season's monitoring data from site S59 – a “snapshot” of its condition 10 to 15 years after the initial dike breach. Although we cannot determine the site's restoration trajectory from one year's data, natural processes and controlling factors have clearly been successfully re-established at the site, and tidal wetland restoration is well underway, with no apparent obstacles to success. Channels are meandering (although branching is less extensive than at most least-disturbed low marsh sites), and channel profiles in some parts of the site are fairly deep and steep-sided (although many of the channels are relatively broad and shallow, probably due to earlier grazing). Tidal inundation is frequent, soils are high in organic matter, and soil and water salinities are typical of brackish tidal marsh. The only major structural alteration still in place is the remaining dike, which undoubtedly reduces sheet flow and may reduce the rate of sediment accretion (Thom *et al.* 2002). The degree to which the dike alters the site's restoration trajectory cannot easily be determined.

During field work, we found no perceptible difference in elevation between mud flats and adjacent, thriving stands of Lyngbye's sedge. Although we did not analyze the mud flat soils, soil test data from the site showed salinity, organic matter content, pH, and texture that appear conducive to further development of tidal marsh. These observations suggest that tidal marsh will continue to expand and develop at the site. In addition, sediment accretion and organic matter accumulation will most likely raise the wetland surface as time passes, further fostering development of tidal marsh or even tidal swamp. However, it is difficult to predict the likelihood of sediment accretion and organic matter accumulation raising the site to its original tidal swamp elevation, particularly in the event of sea level rise.

Although this project did not include formal functional assessment, we spent many hours on each site and made informal observations of wildlife use and conditions. During these field visits, it became clear that site S59 is currently providing important tidal wetland functions, as described below.

Bird habitat: During our field studies at the site, we saw a wide variety of shorebirds, waterfowl and wading birds foraging on the site. The site appears to be providing a high level of the following bird habitat functions (Adamus 2006): 1) ***sustain habitat for nekton-feeding wildlife*** (such as great blue herons); 2) ***sustain habitat for ducks and geese***, and 3) ***sustain habitat for shorebirds***. The site's original tidal swamp habitat probably provided different functions, with greater landbird and songbird use in trees and shrubs, and less shorebird use.

Native plant support: The majority of the site's vegetation consists of native species typical of low marsh; cover of non-native species is low (Table 11). The site is providing the tidal wetland function "*maintain natural botanical conditions*" (Adamus 2006). Although populations of Japanese knotweed were observed on the road embankment adjacent to the site, the site's salinity apparently prevents establishment of this invasive species on the marsh surface. A Japanese knotweed control program was instituted during the course of this study (Jeffrey Jones, personal communication), and the knotweed population has been almost completely eliminated.

Water quality: Site S59 has a meandering channel network, frequent inundation, and areas of dense vegetation. These physical characteristics relate closely to the ability of a tidal wetland to purify water by removing or detaining sediment and pollutants, as does the site's high soil organic matter content (see "Discussion: Soils" above). Clearly, site S59 provides the wetland function listed in Adamus (2005) as "*stabilize and accrete sediment; process carbon, nutrients, and metals.*"

Site S65: Early restoration trajectory and wetland functions

One year after restoration, site S65 was following the desired restoration trajectory. Since the current project provided only a single year's data, we evaluated restoration trajectory in a related project (Brophy 2007b, 2008). Restoration design for site S65 made heavy use of the baseline data collected in the current project. Restoration was implemented in 2007 as offsite mitigation for wetland impacts caused by construction of the North Fork Siuslaw River Bridge (Brophy 2007b). We conducted Year 1 post-restoration effectiveness monitoring in 2008 (Brophy 2008); effectiveness monitoring at this site has been funded for a period of 15 years, a timeline appropriate to the slower pace of recovery at forested wetland sites. We expect that future monitoring at site S65 will provide very useful guidance for restoration of Oregon's outer coast tidal swamps.

We provide a brief summary of Year 1 effectiveness monitoring at site S65 in this section and in "Discussion: Post-restoration trends in plant community composition at site S65" above. For further details, see Brophy (2008).

At the time of Year 1 post-restoration effectiveness monitoring, site S65 met all required performance standards set by the regulatory agencies, and appeared to be following the desired restoration trajectory. Native species dominance was higher than expected by Year 1 after restoration, and survival of woody plantings was 100% through the driest part of summer 2008. Soils and moisture conditions at the site are optimum for establishment of Sitka spruce -- the likely original dominant -- so ultimate re-establishment of Sitka spruce swamp seems likely (J. Jones, Siuslaw Soil and Water Conservation District restoration contractor, personal communication).

Measured tide heights at site S65 matched those at the Siuslaw tidal swamp reference site (S63); the modeled tidal inundation regime most closely matched that of the Yaquina tidal swamp reference site (Y28).

In the North Fork Bridge offsite mitigation project (Brophy 2007b), we assessed wetland functions at site S65 and reference sites S63 and Y28 using the hydrogeomorphic (HGM) method. Briefly, for almost all assessed functions, the reference sites had substantially higher functions compared to pre-restoration conditions at site S65. Functions that were especially high at the reference sites were anadromous fish habitat, invertebrate habitat, and water quality. Predicted functional “lift” at restoration site S65 was high for all of these functions.

We also made informal observations of wildlife use at site S65 (as we did at all of the sites). Juvenile coho were observed foraging in the site’s restored channel less than 1 year after restoration in spring 2009 (Jeff Jones, Siuslaw SWCD restoration contractor, personal communication). Deer, elk and bear use the site heavily, based on observation of tracks, browse on woody plantings, and damage to groundwater well installations. These observations suggest that the site is performing wildlife habitat functions at a high level.

Recommendations for future monitoring

Future monitoring at the study sites should follow standards established by regional and national guidance documents. References to these documents are found in Brophy (2007a); comprehensive regional guidance can be found in Roegner *et al.* (2008).

Specific recommendations include:

- Monitor salinity and groundwater level on higher elevation areas of Cox Island (site S11) to explore possible restoration of spruce swamp.
- Repeat vegetation and soil sampling at the permanent plots established in this study.
- Use “partial replacement” sampling. This method has been shown to improve analytical power when studying change in tidal wetland vegetation (Tear 1995).
- Add new data to bar charts in vegetation spreadsheets to assist visualization of vegetation change over time. See Cornu and Sadro (2002) for examples.
- Using future vegetation data, recalculate t-test and similarity index comparisons of plant community composition. Add calculations of change over time; see Thom et al. (2002) for examples.
- For site S59, as the restoration trajectory progresses, add t-test and similarity index comparisons to Reference site S63, to evaluate trajectory relative to the site’s historic pre-disturbance condition.
- Revise this project’s maps of major vegetation types using updated aerial orthophotos to quantify large-scale site changes.
- Create detailed vegetation maps similar to those developed for other restoration sites (e.g. Brophy and Christy 2008, Brophy 2005c, 2007c). Re-map at intervals to track plant community changes and restoration trajectory.

- Measure sediment accretion and organic accumulation to help estimate time to recovery of original site elevations. Incorporate estimates of sea level rise in interpreting data.
- Monitor changes in soil conditions over time, particularly organic matter content. This metric relates closely to disturbance levels, site recovery, and wetland functions.
- Measure channel morphology (channel width and depth, length, bifurcation ratio, and sinuosity) and compare measurements at restoration and reference sites
- Document beaver activity, Sitka spruce root platform development, and accumulation of large woody debris to improve understanding of “system engineers” in tidal swamp development.

Collaborative and related projects

This project had the benefit of many collaborative relationships and related projects which extended monitoring far beyond the original scope of work. Reports from these related projects have been provided to Ecotrust and to EPA. Reports are cited and projects are briefly described below.

Brophy, L.S. (Green Point Consulting). 2007. Offsite Mitigation Plan: North Fork Siuslaw River Bridge. Prepared for Siuslaw Soil and Water Conservation District and Oregon Department of Transportation. 81 pp.

Tidal swamp restoration at site S65 was implemented in 2007 as part of mitigation for wetland impacts associated with construction of the new North Fork Siuslaw River Bridge. The Off-site Mitigation Plan contains design details, reference data, baseline monitoring data for the restoration site, a wetland delineation, functional assessment, and performance standards for the restoration work.

Brophy, L.S. (Green Point Consulting). 2008. Annual Compensatory Wetland Mitigation Monitoring Report 2008: Off-site Mitigation, North Fork Siuslaw River Bridge Project. Prepared for Siuslaw Soil and Water Conservation District. 45 pp.

This document contains Year 1 post-restoration monitoring results for the tidal swamp restoration at site S65.

Brophy, L.S. (Green Point Consulting). 2007. Vegetation monitoring and mapping at tidal wetland restoration and reference sites: Siletz Bay National Wildlife Refuge and Yaquina River Estuary. Prepared for Confederated Tribes of Siletz Indians, Siletz, OR. 42 pp.

This project documents post-restoration effectiveness monitoring at tidal wetland restoration sites in the Siletz and Yaquina River estuaries, along with monitoring at paired reference sites. Site Y28 served as a reference site for the nearby restoration site (Y27). Vegetation was monitored and mapped at all sites.

Brophy, L.S. (Green Point Consulting), Paul Adamus, John Christy, Craig Cornu, Julie Custer, Rebecca Tully and Craig Young. (*in preparation*). In-Situ Multichannel Wireless Sensor Networks and iButton Temperature Logger Arrays for Characterizing Habitat Drivers in Tidal Wetland Reference Sites. Final report to the Cooperative Institute for Coastal and Estuarine Environmental Technology.



In a project funded by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), we measured controlling factors, structure, and function in least-disturbed tidal wetlands of the Oregon coast (Brophy *et al.* 2008, 2009, and in preparation). Three tidal swamps were studied: a brackish spruce swamp in the Nehalem River estuary, and a freshwater tidal swamp in the Columbia River estuary that included both willow and spruce vegetation types, and Site Y28. (Site Y28 was a pilot site with a limited monitoring program, but monitoring included groundwater and modeling of the tidal inundation regime.) One of the products from the CICEET project is a pilot

reference conditions database to assist restoration design in tidal wetlands of Oregon. Similar methods were used in the CICEET project and the current study, so the data can be compared. Preliminary results are provided in the CICEET project progress reports (e.g. Brophy 2008, 2009), available online at the CICEET Project Explorer website (www.ciceet.unh.edu); final results will be compiled in the project final report (Brophy *et al.*, in preparation).

Products from this study

The following products are provided with this report:

Zipped ArcView shapefiles:

1. Study sites, extracted from Brophy (2005): SiusEPAMonitoringSites.zip
2. Permanent plot central axis endpoints, Site S11: S11_trscpts06.zip
3. Permanent plot central axis endpoints, Site S59: S59_trscpts06.zip
4. Permanent plot central axis endpoints, Site S63: S63_trscpts06.zip
5. Permanent plot central axis endpoints, Site S65: S65_trscpts06_07.zip
6. Permanent plot central axis endpoints, Site Y28: Y28_trscpts06.zip
7. Restoration site S59: map of vegetation types (polygon features, S59_HGM_polys.zip)
8. Restoration site S65: map of vegetation types (polygon features, S65_HGM_polys_refined1.zip)

Excel spreadsheets:

1. summary of tidal inundation regimes (Sius_Ecotrust_all-sites_TIR-summary_forEPA.xls)
2. summary of surveyed elevations (All-sites_Elev-summary_forEPA.xls)
3. groundwater manual observation datafile (S63-65_groundwater_13mar-12jun07_forEPA.xls)
4. surface water salinity data (Sius_salinities_all-sites_forEPA.xls)
5. soil test results (SoilSummary_Sius_forEPA.xls)
6. herbaceous vegetation data and summaries (Sius_herb_2006-all-sites-summary_forEPA.xls)
7. woody vegetation data and summaries, SiteS63 (Sius_woody_2006-S63_forEPA.xls)
8. woody vegetation data and summaries, site S65 (Sius_woody-LWD__2006-2008-S65_forEPA.xls)
9. woody vegetation data and summaries, Site Y28 (Sius_woody_2006-Y28_forEPA.xls)

Onset HOBOWare Pro project files (used with HOBOWare Pro software):

1. groundwater vs. tides at site S63 (S63_groundwater-vs-Y28tides_forEPA.hproj)
2. groundwater vs. tides at site S65 (S65_groundwater-vs-Y28tides_forEPA.hproj)
3. groundwater vs. tides at Site Y28 (Y28GW-vs-tides_forEPA.hproj)

All Excel spreadsheets and Onset HOBOWare files are bundled into a single zipped file.

List of tables, figures, and maps

Tables

- Table 1. Study site characteristics
- Table 2. Monitoring parameters
- Table 3. Monitoring timeline
- Table 4. Summary of monitoring methods
- Table 5. Study plot sizes
- Table 6. Elevations of study plots
- Table 7. Elevations of site features and instrumentation
- Table 8. Tidal datums for study sites
- Table 9. Average surface water salinity
- Table 10. Soil test results
- Table 11. Summary of plant community composition: low marsh
- Table 12. Summary of plant community composition: high marsh
- Table 13. Summary of plant community composition: tidal swamp
- Table 14. Similarity index for S59 compared to S11 Plot 3
- Table 15. Similarity index in 2006 and 2008 for S65 compared to S63 Plot 2
- Table 16. Woody stem densities at tidal swamp sites
- Table 17. Landscape setting data

Figures

- Figure 1. Water table depth in March to June 2007 at tidal swamp restoration site S65 and reference site S63
- Figure 2. Groundwater fluctuation vs. tide cycles at reference Site S63
- Figure 3. Groundwater fluctuation vs. tide cycles at restoration Site S65
- Figure 4. Groundwater fluctuation vs. tide cycles at reference Site Y28 in spring
- Figure 5. Groundwater fluctuation vs. tide cycles at reference Site Y28 in late summer
- Figure 6. Species richness for study plots
- Figure 7. Pre-restoration vs. post-restoration plant community composition, Site S65
- Figure 8. Weighted similarity index in 2006 and 2008 for S65 vs. S63 Plot 2
- Figure 9. Unweighted similarity index in 2006 and 2008 for S65 vs. S63 Plot 2
- Figure 10. Tidal swamp restoration Site S65: Changes in cover for major dominant species, 2006-2008
- Figure 11. Tidal swamp restoration Site S65: Changes in cover for minor species, 2006-2008
- Figure 12. Soil salinity vs. summer surface water salinity at Siuslaw and Yaquina study sites

Appendices

- Appendix 1. Maps
- Appendix 2. Additional figures
- Appendix 3. Photos of Site S65 tidal swamp restoration
- Appendix 4. General site photos
- Appendix 5. QAPP
- Appendix 6. Modifications to QAPP

Appendix 1: Maps

- Map 1. Locator map: Study sites in the Siuslaw River estuary
- Map 2. Locator map: Yaquina tidal swamp reference site (Site Y28)
- Map 3. Historic vegetation of the lower Siuslaw River estuary
- Map 4. Site S11 study plots
- Map 5. Site S59 study plots
- Map 6. Site S63 study plots
- Map 7. Site S65 study plots
- Map 8. Site Y28 study plot
- Map 9. Site S65 restoration design
- Map 10. Site S59 vegetation types
- Map 11. Site S65 vegetation types

Appendix 2: Additional figures

- Figure A1. Reference site S11: Tidal inundation frequency (days)
- Figure A2. Restoration site S59: Tidal inundation frequency (days)
- Figure A3. Reference site S63: Tidal inundation frequency (days)
- Figure A4. Restoration site S65: Modeled tidal inundation frequency (days) after implementation of restoration
- Figure A5. Reference site Y28: Tidal inundation frequency (days)
- Figure A6. Reference site S11: Tidal inundation frequency (percent)
- Figure A7. Restoration site S59: Tidal inundation frequency (percent)
- Figure A8. Reference site S63: Tidal inundation frequency (percent)
- Figure A9. Restoration site S65: Modeled tidal inundation frequency (percent) after implementation of restoration
- Figure A10. Reference site Y28: Tidal inundation frequency (percent)
- Figure A11. Dike effect at tidal swamp restoration site S65.
- Figure A12. Reference site S63: Effect of river flows on tidal inundation frequency
- Figure A13. Restoration site S65: Effect of river flows on tidal inundation frequency after implementation of restoration
- Figure A14. Reference site S63: Effect of river flows on percent inundation
- Figure A15. Restoration site S65: Effect of river flows on percent inundation after implementation of restoration
- Figure A16. Tidal Marsh Reference Site S11 (Cox Island): Plant community composition
- Figure A17. Tidal Marsh Restoration Site S59: Plant community composition
- Figure A18. Tidal Swamp Reference Site S63: Plant community composition
- Figure A19. Tidal Swamp Reference Site Y28: Plant community composition

Appendix 4: General site photos

- Photo A1. September 10, 2007: Setting of Site S65 on the North Fork Siuslaw River
- Photo A2. September 10, 2007: South-facing aerial view of Site S65 immediately after restoration
- Photo A3. August 14, 2007: Excavation of pilot channel at Site S65
- Photo A4. August 14, 2007: Rising tide fills the dike breach at Site S65
- Photo A5. September 27, 2007: Site S65: Spring high tide fills the pilot channel and dike breach area

Photo A6. March 17, 2008: Site S65 north-facing view of dike breach and former pasture
Photo A7. August 3, 2006: Student volunteer Sam Waterhouse stands in tidal channel in
Y28 spruce swamp
Photo A8. June 20, 2006: Sitka spruce swamp, Site S63
Photo A9. January 4, 2007: Willow scrub-shrub tidal wetland, Site S63 Plot 1
Photo A10. February 20, 2006: Laura Brophy conducts initial site reconnaissance in willow
scrub-shrub tidal wetland, Site S63
Photo A11. May 31, 2006: North Fork Siuslaw River in brackish Sitka spruce tidal swamp
zone
Photo A12. January 4, 2007: Diked pastures on the North Fork Siuslaw River, winter high
tide during a high river flow event
Photo A13. January 4, 2007: Cattle move to high ground in flooded pastures
Photo A14. September 6, 2007: Northeast-facing aerial view of North Fork Siuslaw River
study sites (S59, S63 and S65)
Photo A15. September 6, 2007: East-facing aerial view of site S59
Photo A16. September 6, 2007: South-facing aerial view of Cox Island (Site S11)
Photo A17. July 1, 2006: Diverse high marsh flora at Cox Island on high natural levee

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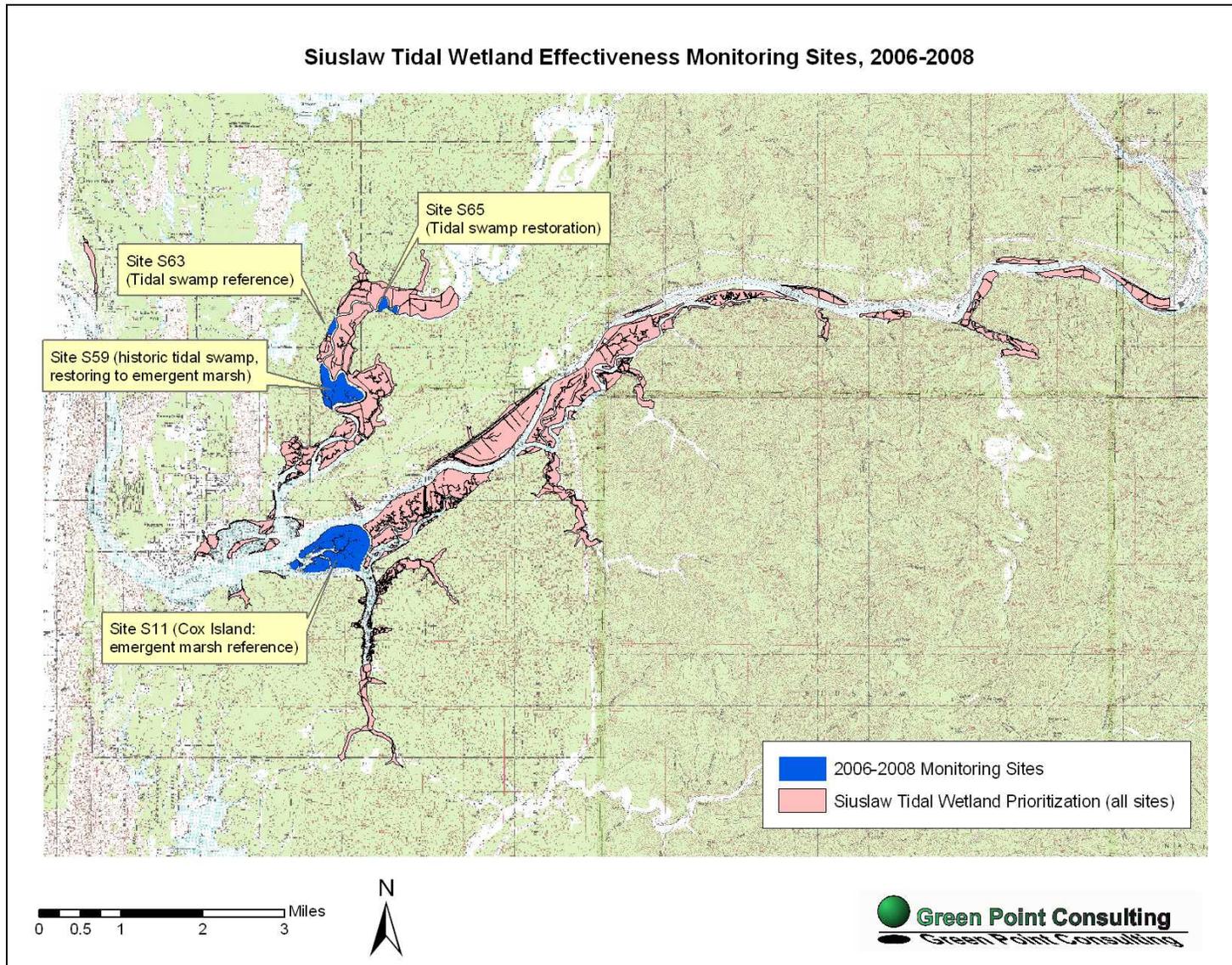
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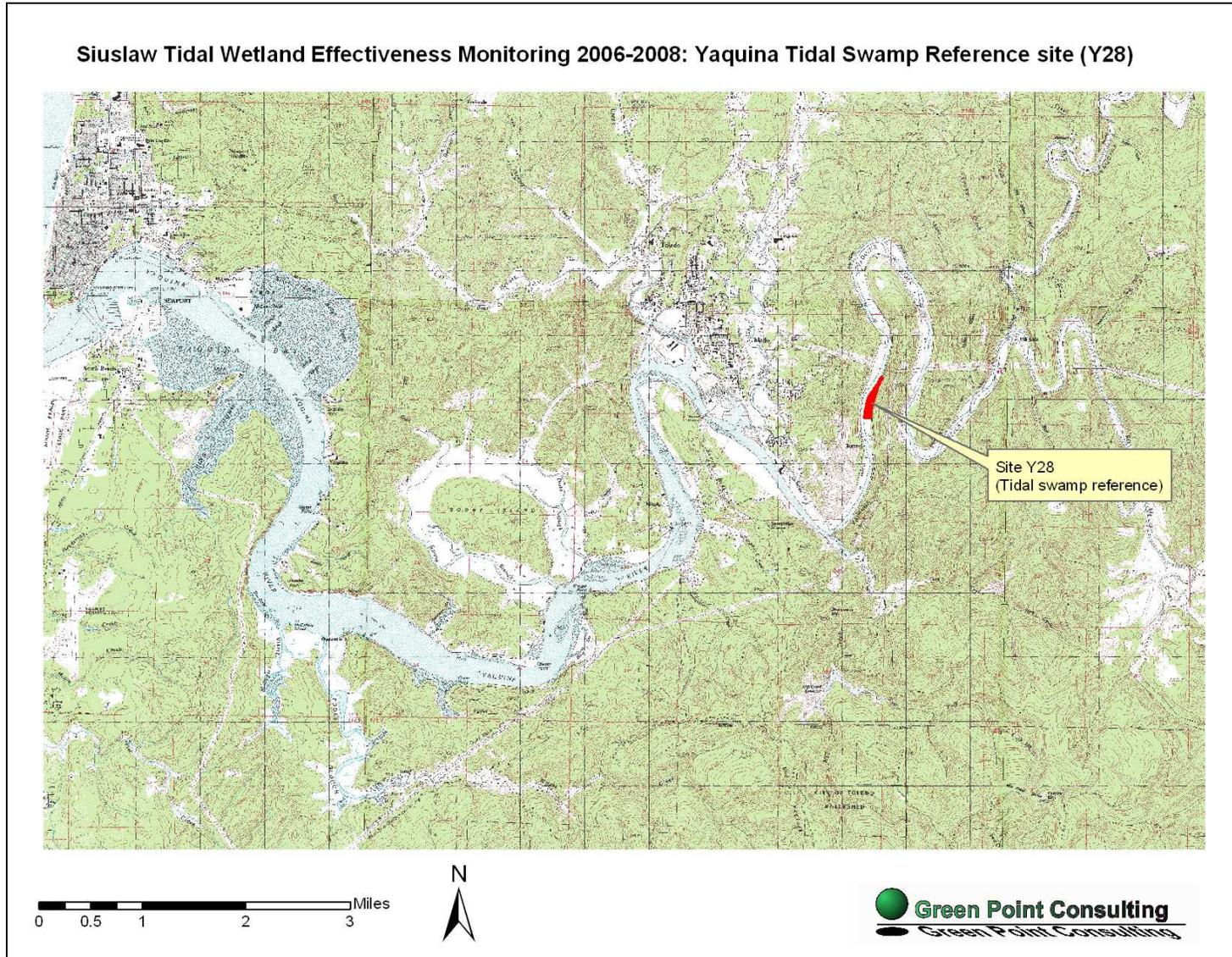
Zedler, J. B. 2001. Handbook for restoring tidal wetlands. CRC Press, Boca Raton, FL.

Appendix 1. Maps

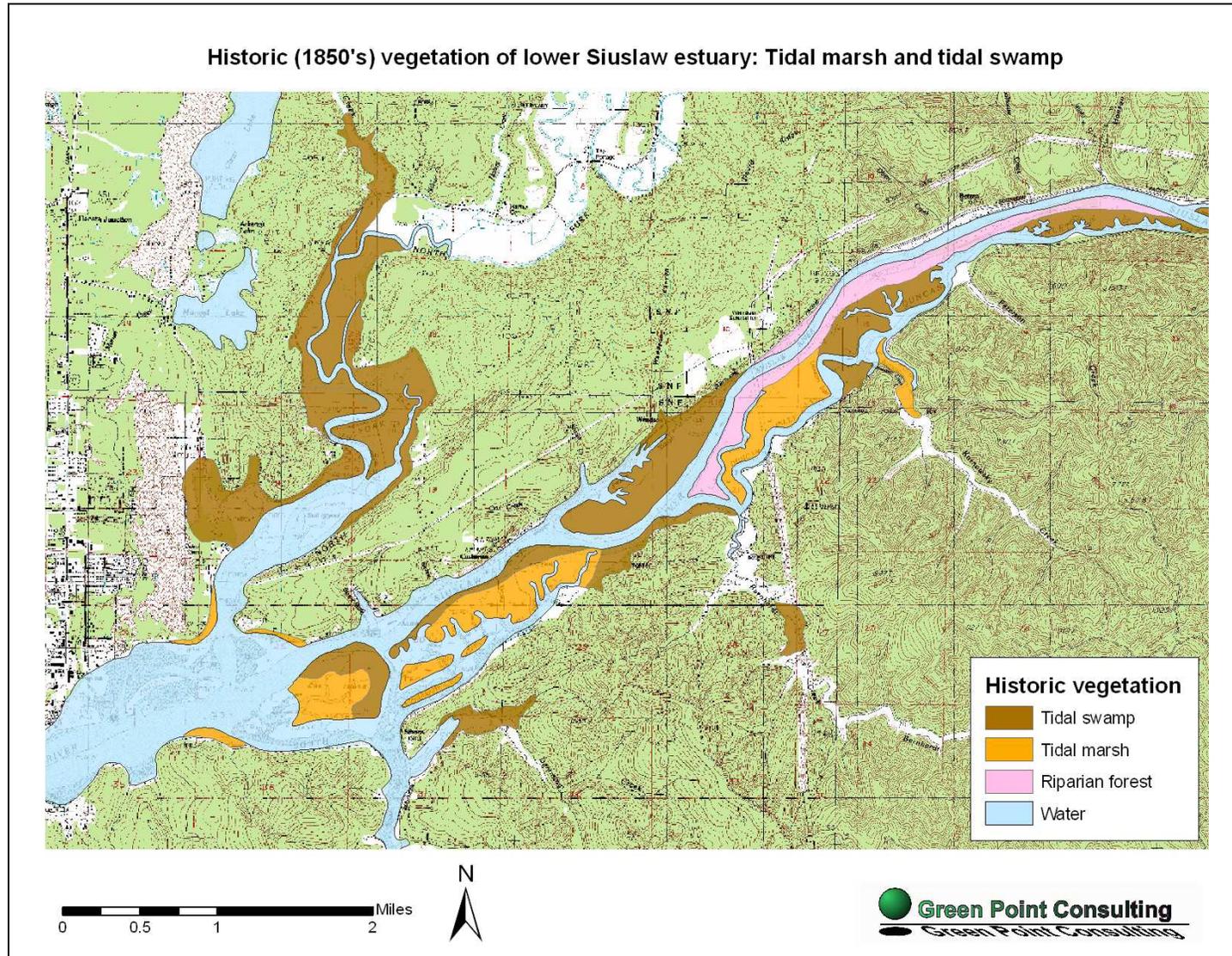
Map 1. Locator map: Study sites in the Siuslaw River estuary.



Map 2. Locator map: Yaquina tidal swamp reference site (Site Y28).



Map 3. Historic wetland and riparian vegetation of the lower Siuslaw River estuary, based on General Land Office surveys of the 1850s (Hawes *et al.* 2002). Areas not classified were mapped as uplands in Hawes *et al.* 2002. Background is USGS topographic map.



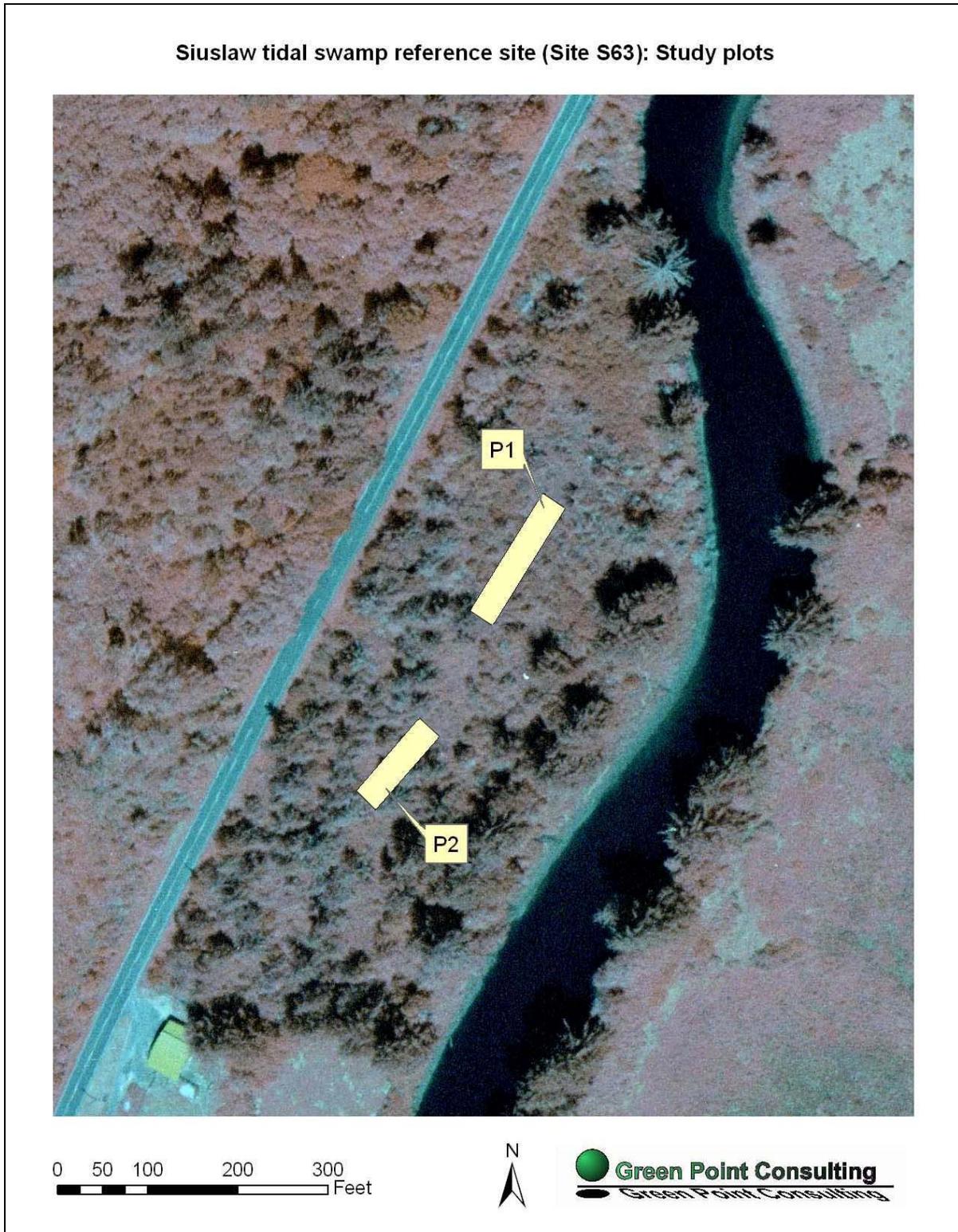
Map 4. Cox Island (site S11) study plots. Background is a 2005 color infrared aerial orthophoto, provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency. (Differential color saturation on east and west halves of Cox Island is an artifact of photo digitization.)



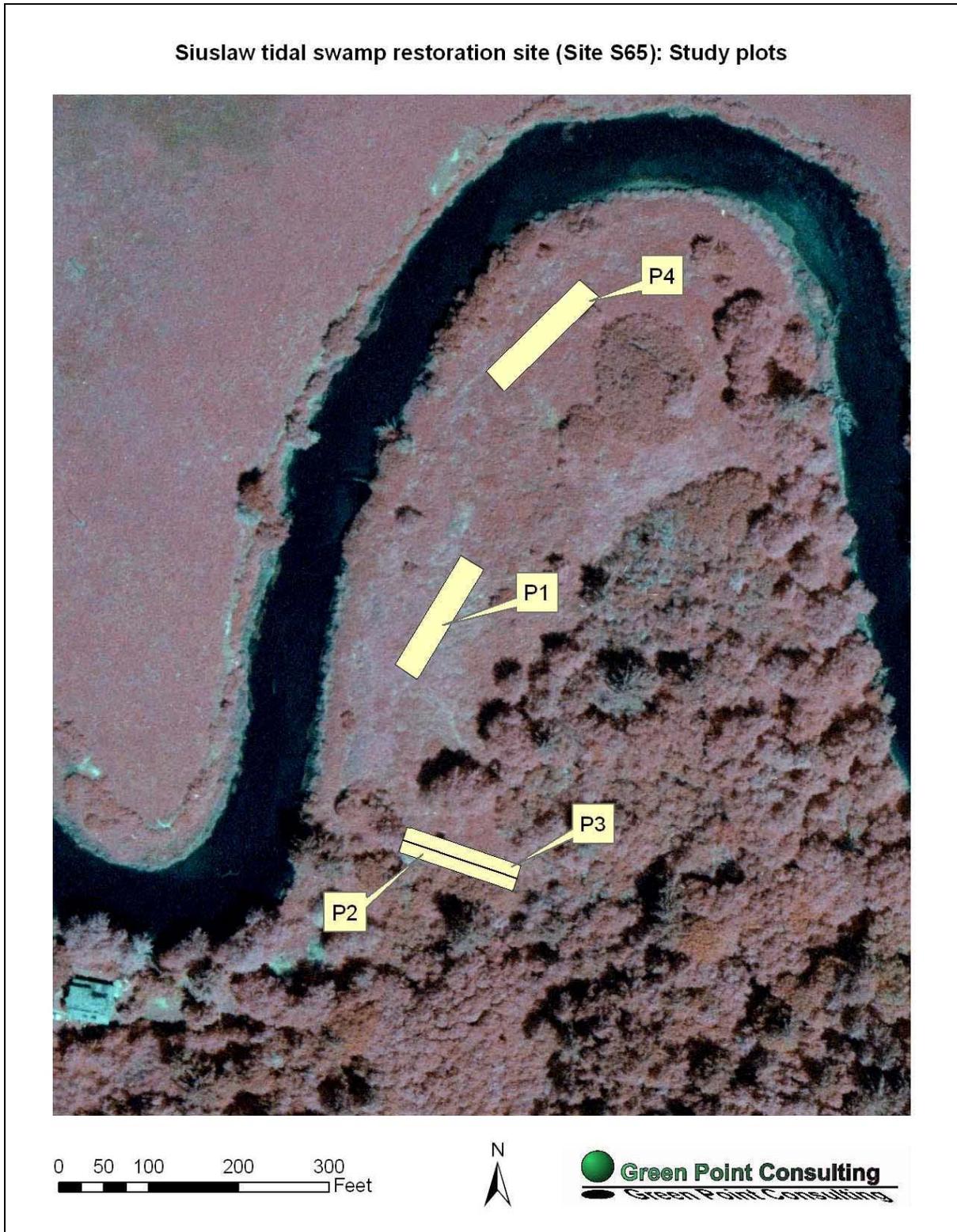
Map 5. Site S59 study plots. Background is a 2005 color infrared aerial orthophoto, provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency.



Map 6. Site S63 study plots. Background is a 2005 color infrared aerial orthophoto, provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency.



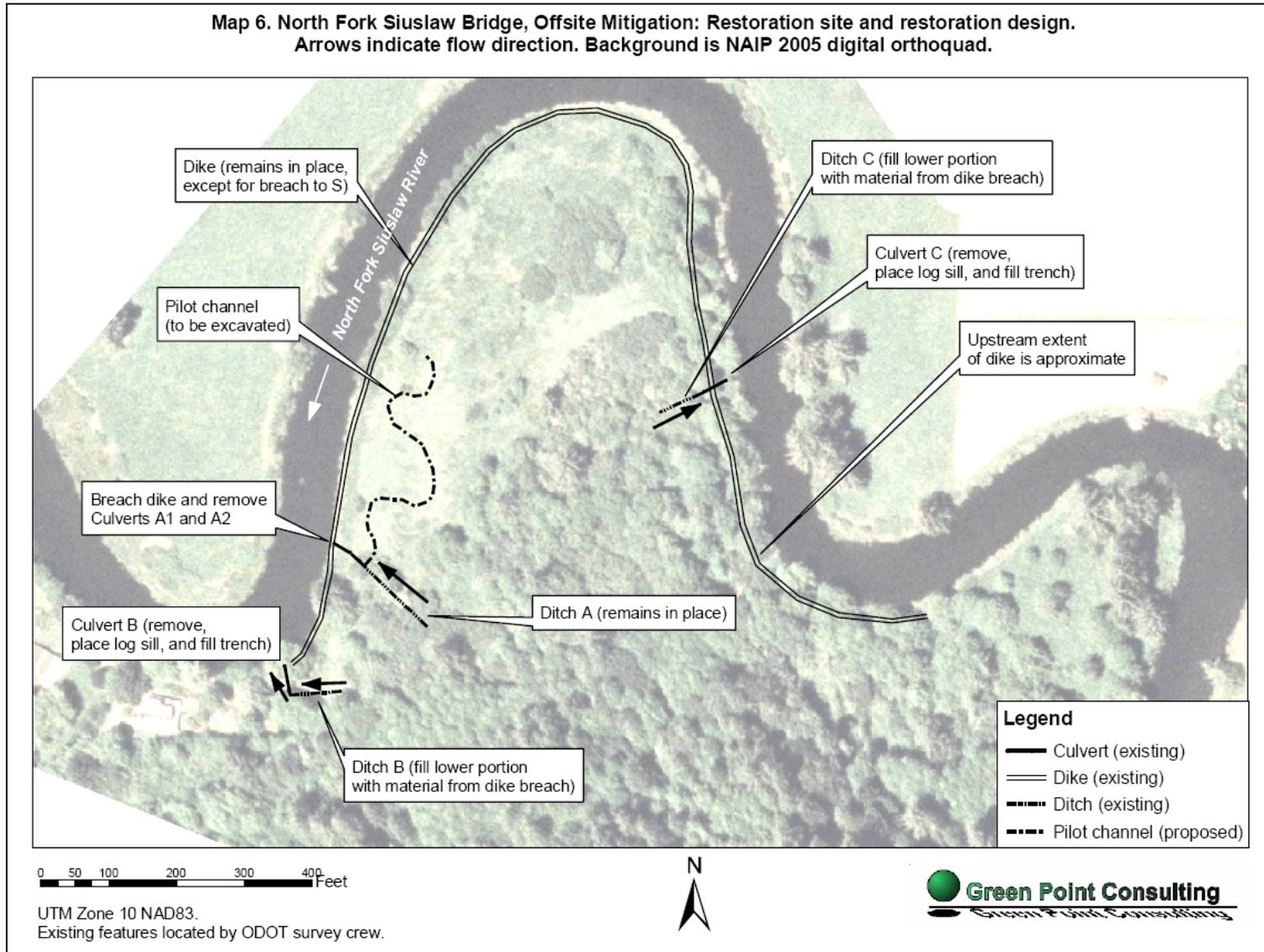
Map 7. Site S65 study plots. Background is a 2005 color infrared aerial orthophoto, provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency.



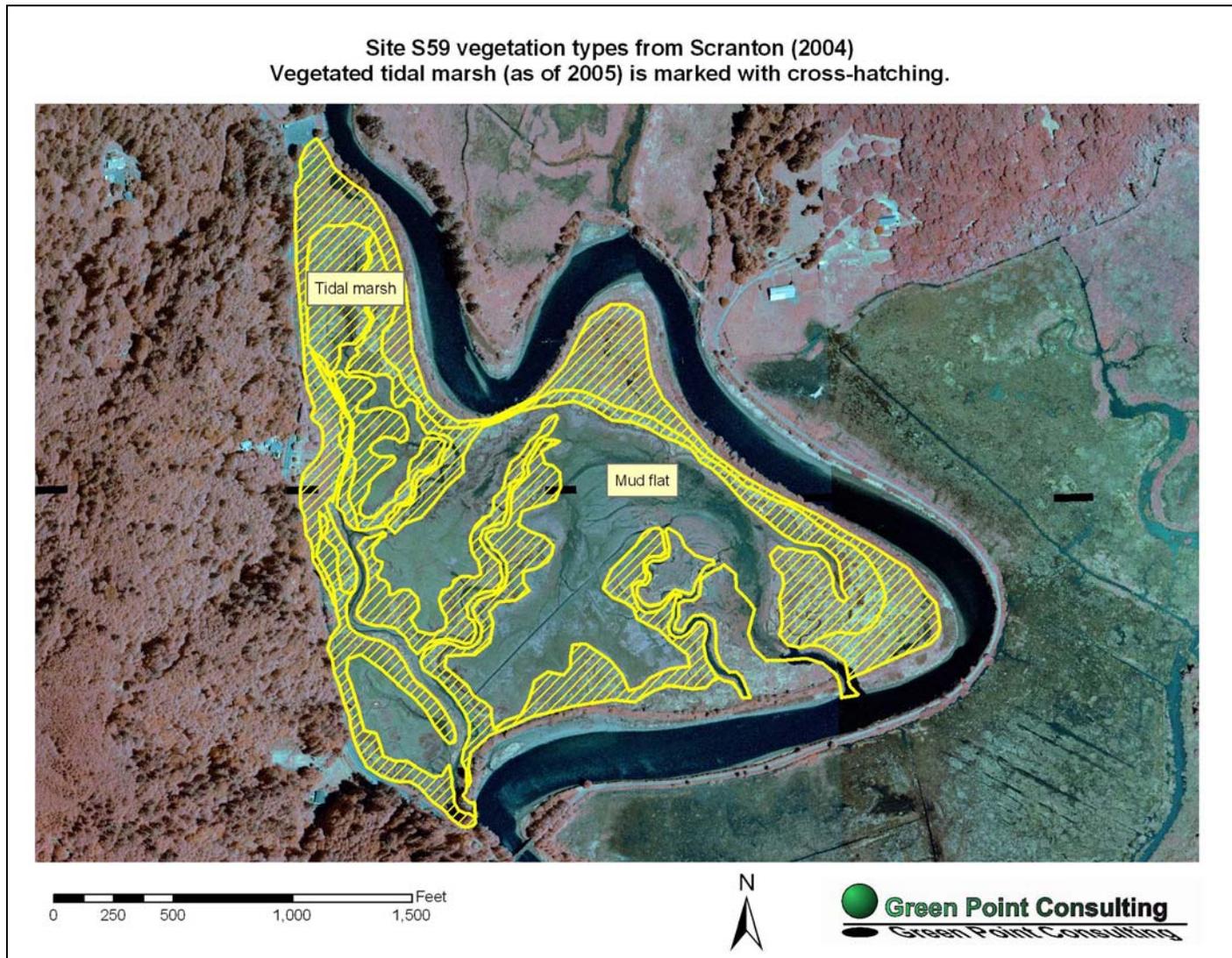
Map 8. Site Y28 study plot. Background is a 2005 color infrared aerial orthophoto, provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency.



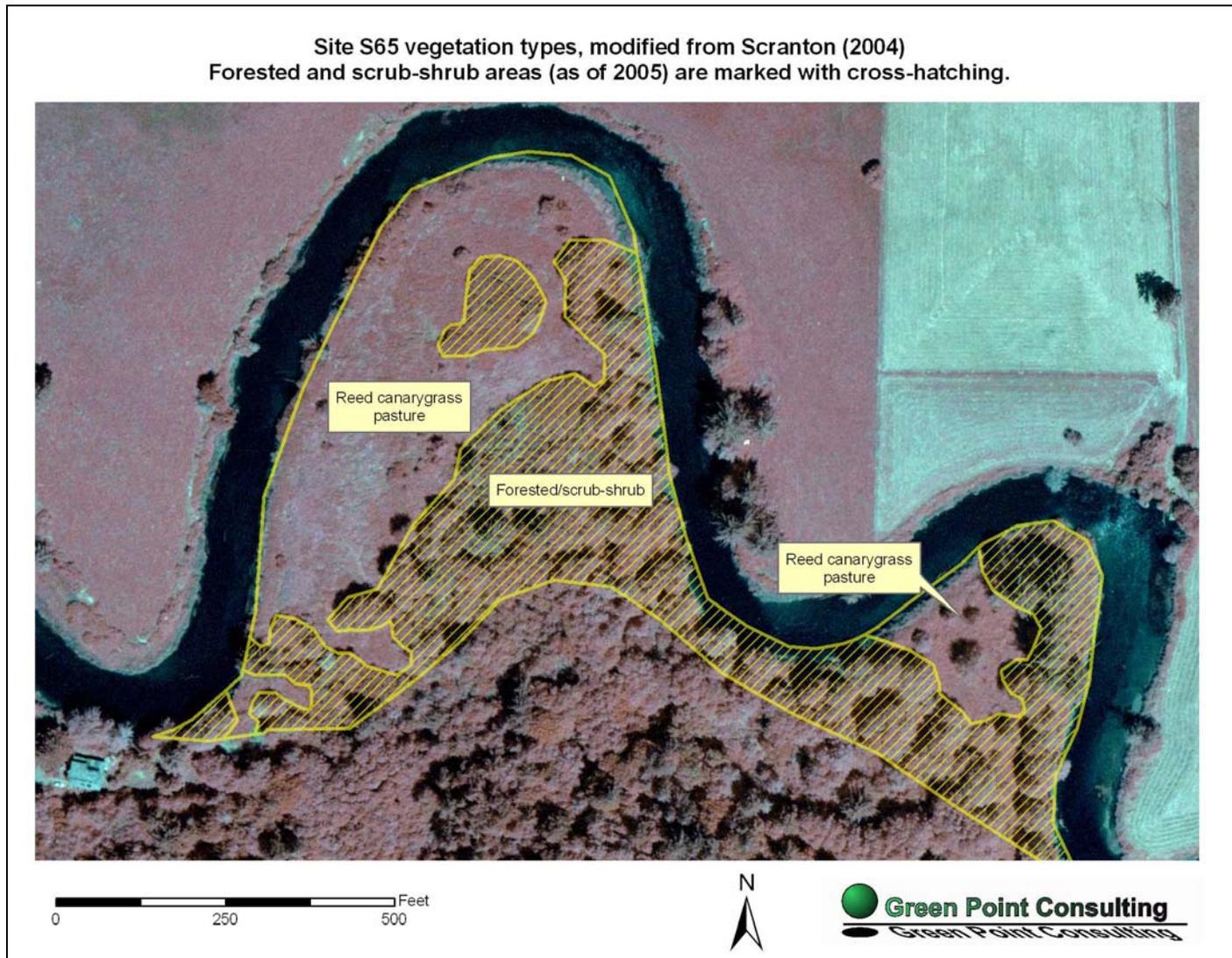
Map 9. Restoration design for site S65. Restoration was implemented in 2007 under a separate project; full details are provided in that project's report (Brophy 2007b) and the first annual monitoring report (Brophy 2008).



Map 10. Vegetation types at site S59 in 2004, from Scranton (2004). “Tidal marsh” includes areas mapped as low marsh (MSL) and high marsh (MSH) by Scranton; “mud flat” was mapped as “water” by Scranton. Background is a 2005 color infrared aerial orthophoto, provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency.



Map 11. Vegetation types at site S65 in 2005 (prior to restoration), modified from Scranton (2004). Boundaries have been refined by heads-up digitization from the background image (a 2005 color infrared aerial orthophoto provided by the Oregon Department of Land Conservation and Development and U.S. Environmental Protection Agency).



Appendix 2. Additional figures

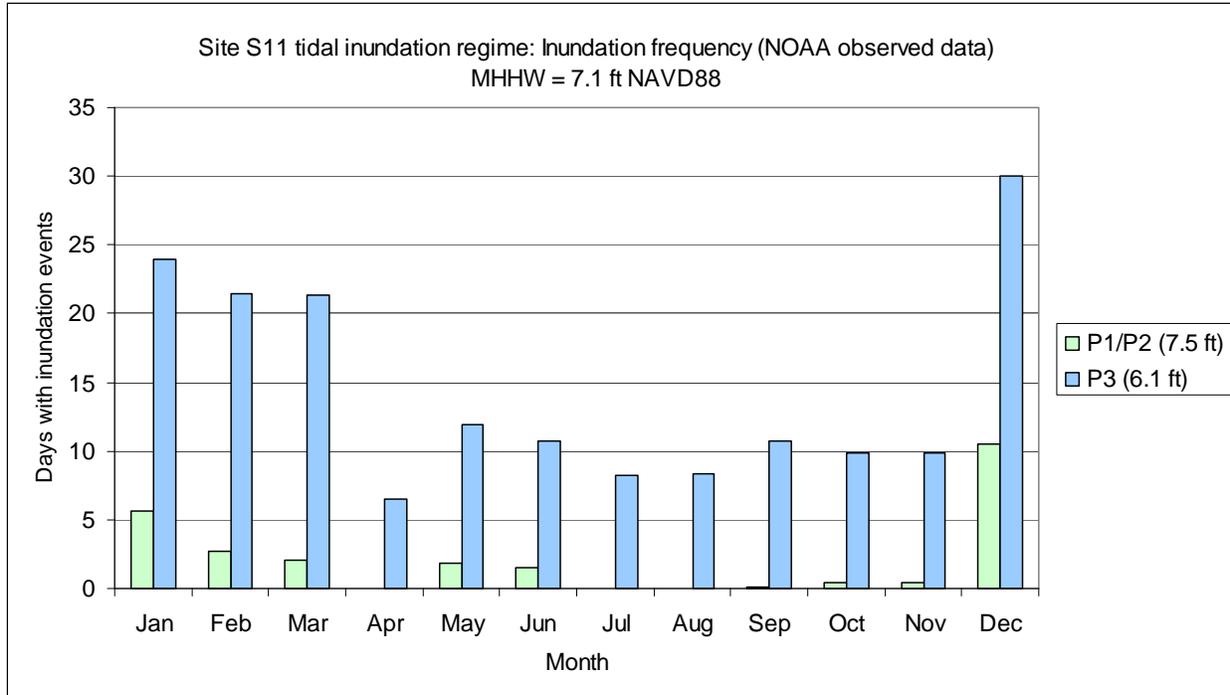


Figure A1. Cox Island reference site (S11): Tidal inundation frequency (days with inundation events), based on NOAA full year record (1933) at nearest tide station (Florence). Plot elevations are NAVD88.

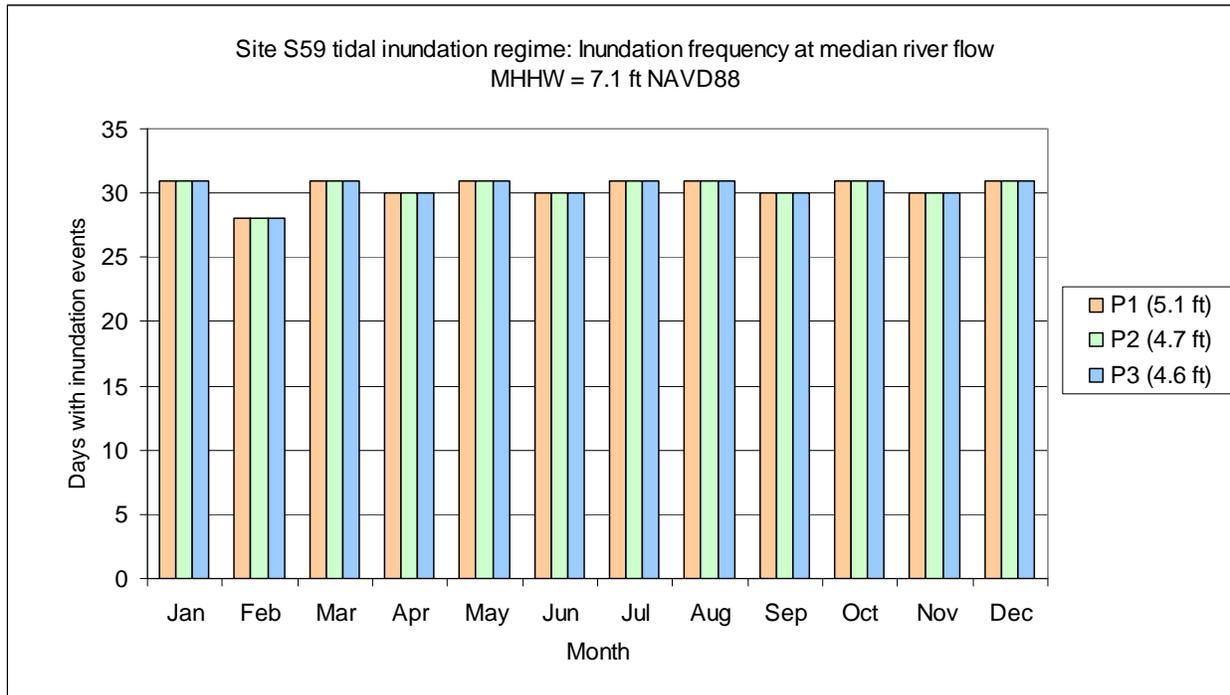


Figure A2. Restoration site S59: Tidal inundation frequency (days with inundation events), based on local inundation model (tide heights plus river flow effect). Plot elevations are NAVD88.

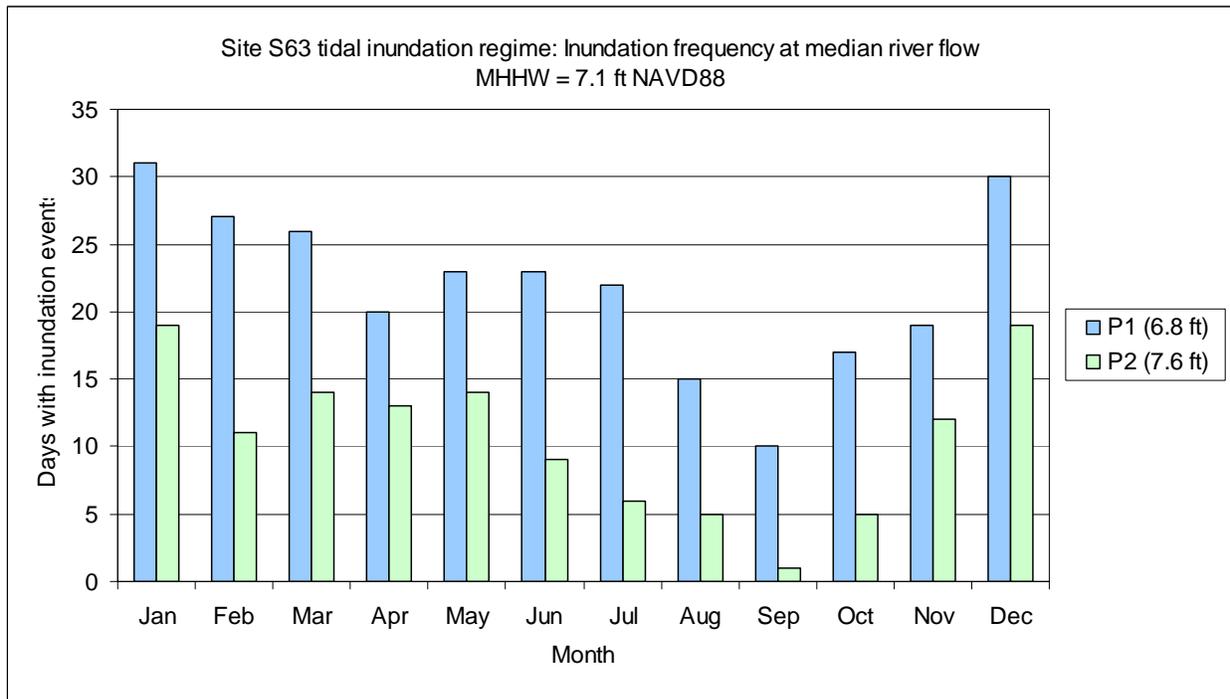


Figure A3. Reference site S63: Tidal inundation frequency (days with inundation events), based on local inundation model (tide heights plus river flow effect). Plot elevations are NAVD88.

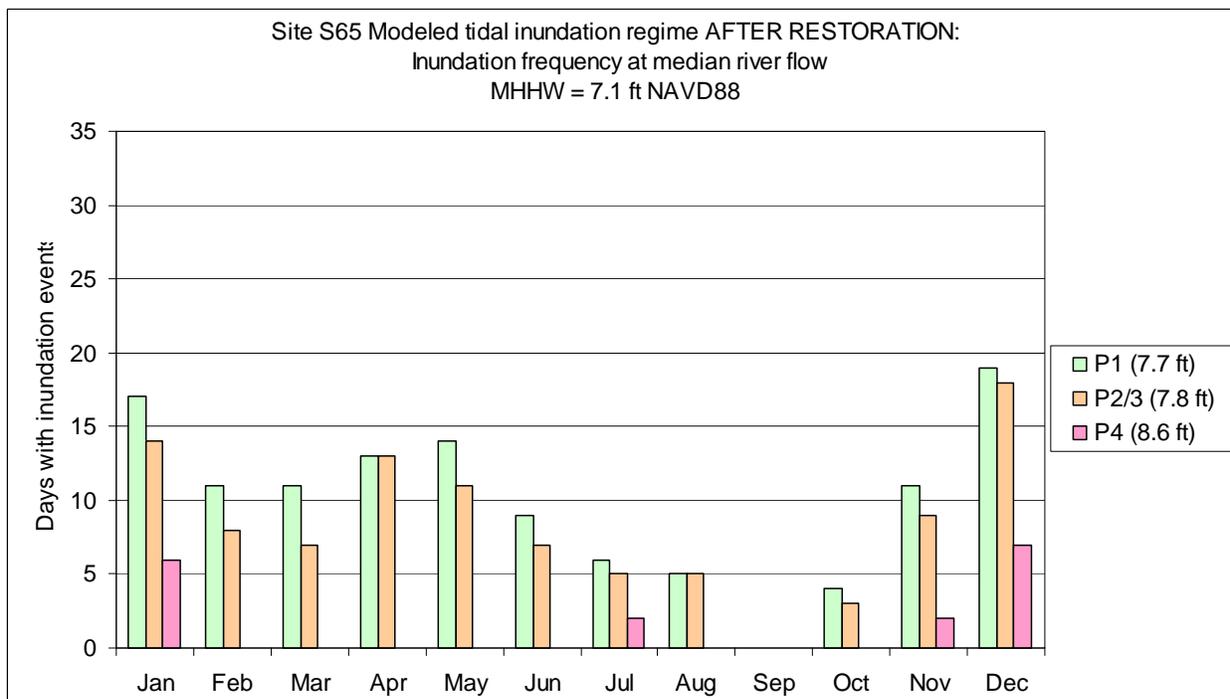


Figure A4. Restoration site S65: Modeled tidal inundation frequency (days with inundation events) after implementation of restoration, based on local inundation model (tide heights plus river flow effect). Plot elevations are NAVD88.

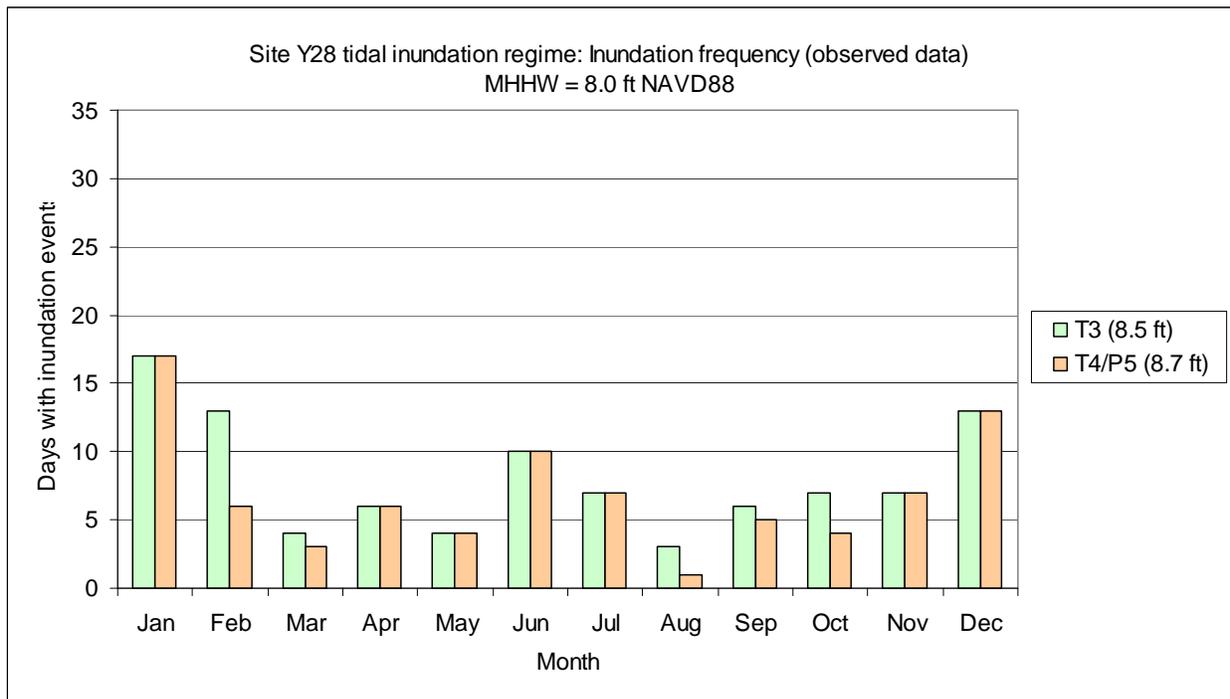


Figure A5. Reference site Y28: Tidal inundation frequency (days with inundation events), based on full-year local tide gauge records during 2007-2008. Plots T3 and T4 were monitored in a separate project (Brophy 2007c); results are shown here for comparison. Plot elevations are NAVD88.

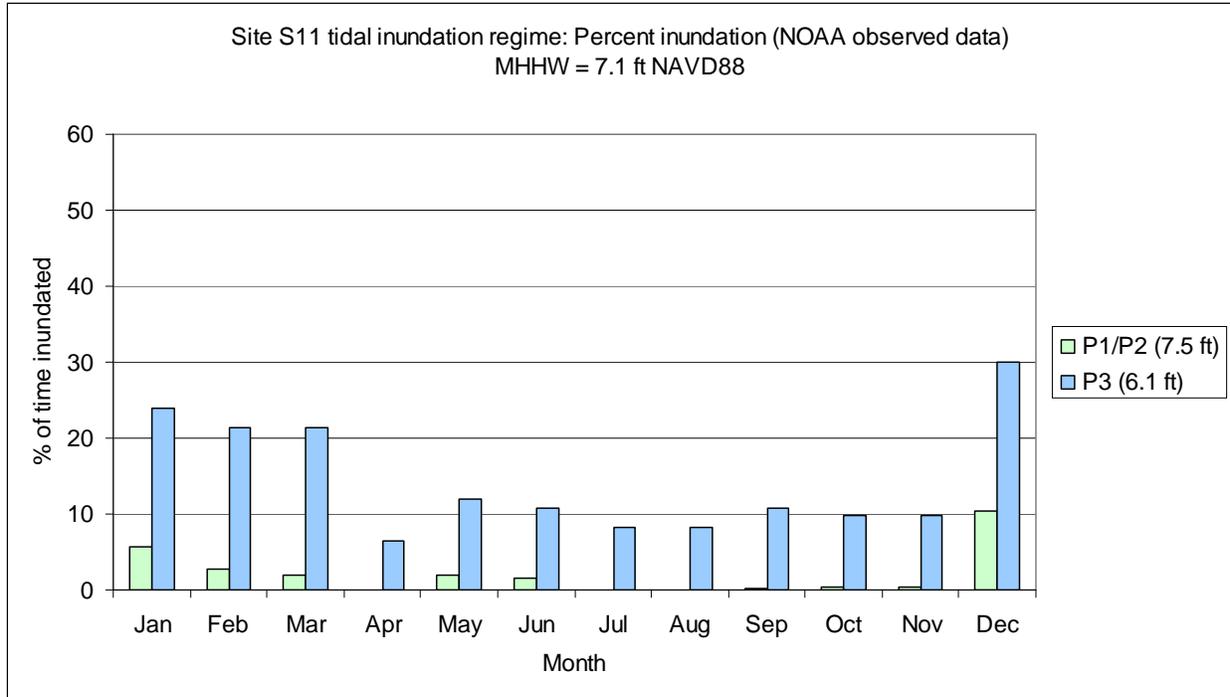


Figure A6. Cox Island reference site (S11): Tidal inundation frequency (percent of time inundated), based on NOAA full year record (1933) at nearest tide station (Florence). Plot elevations are NAVD88.

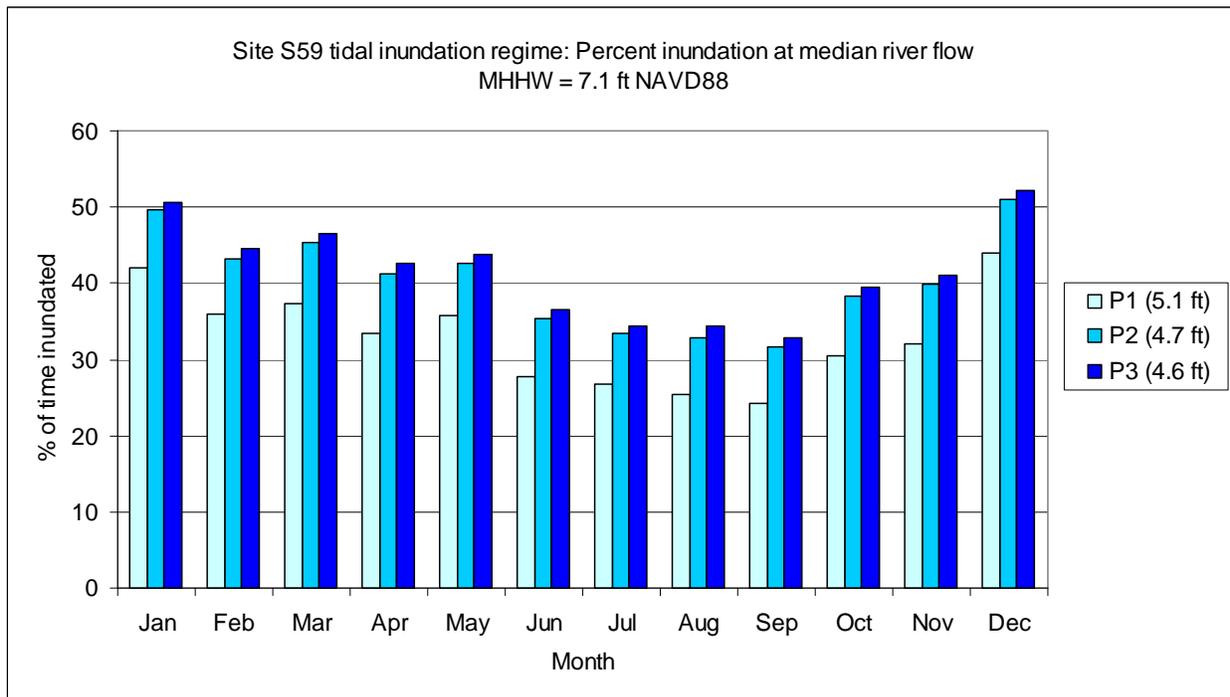


Figure A7. Restoration site S59: Tidal inundation frequency (percent of time inundated), based on local inundation model (tide heights plus river flow effect). Plot elevations are NAVD88.

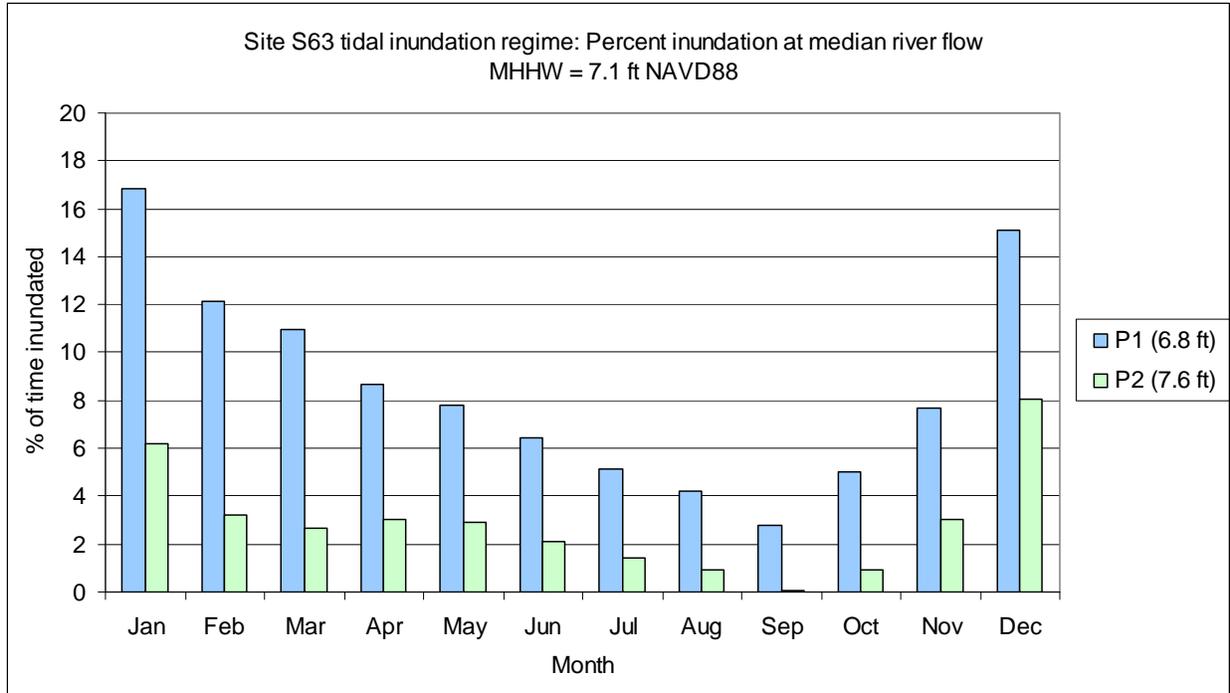


Figure A8. Reference site S63: Tidal inundation frequency (percent of time inundated), based on local inundation model (tide heights plus river flow effect). Plot elevations are NAVD88.

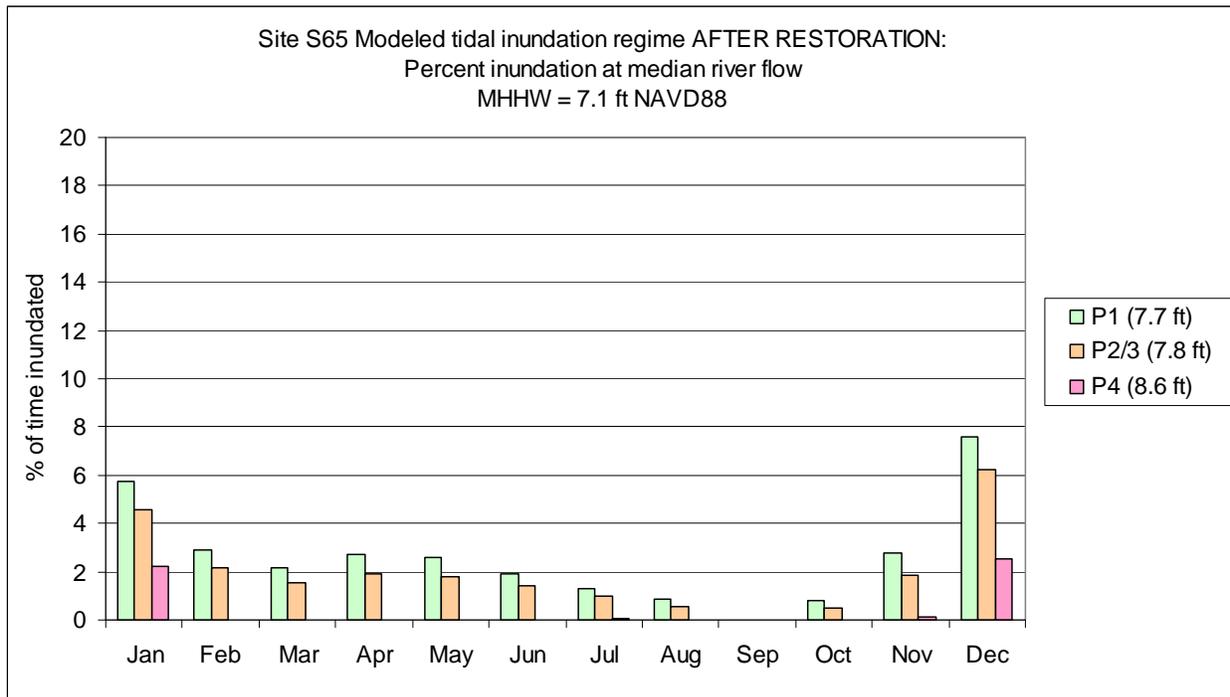


Figure A9. Restoration site S65: Modeled tidal inundation frequency (percent of time inundated) after implementation of restoration, based on local inundation model (tide heights plus river flow effect). Plot elevations are NAVD88.

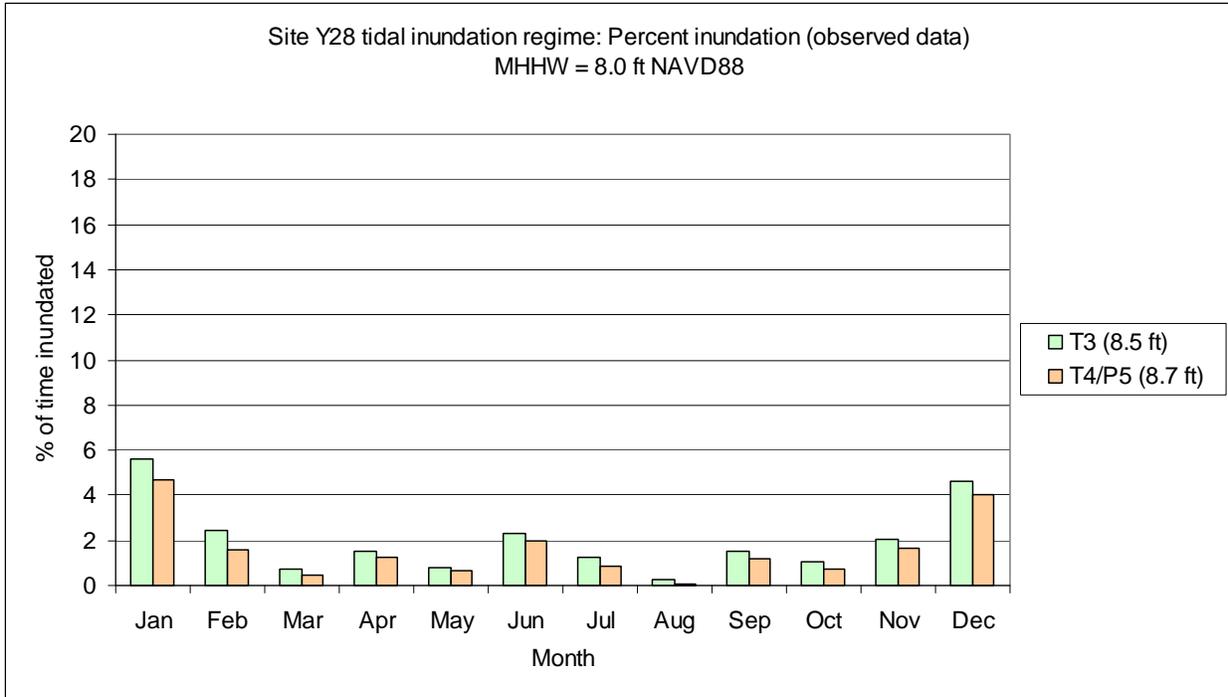


Figure A10. Reference site Y28: Tidal inundation frequency (percent of time inundated), based on full-year local tide gauge records during 2007-2008. Plot elevations are NAVD88.

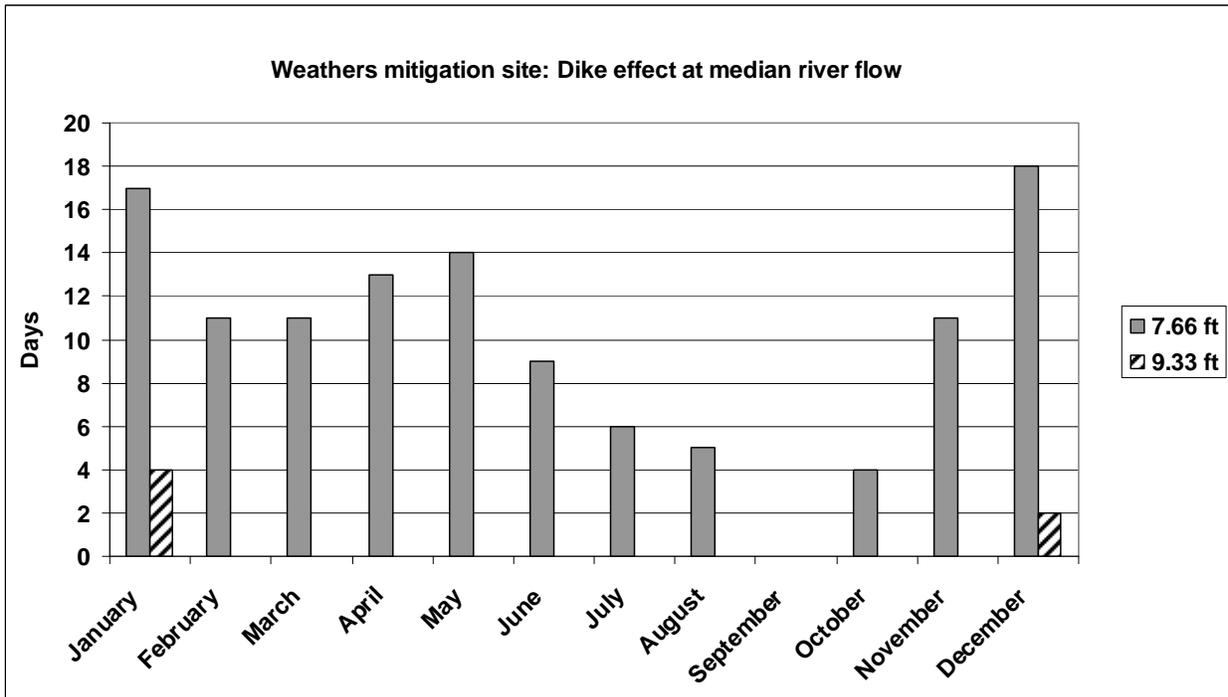


Figure A11. Dike effect at tidal swamp restoration site S65 at median river flows. Striped bars indicate modeled dike overtopping events; gray bars indicate predicted post-restoration tidal inundation regime at Plot 1 after dike breaching. 9.33' = typical dike ht; 7.66' elevation at plot 1. Plot elevations are NAVD88.

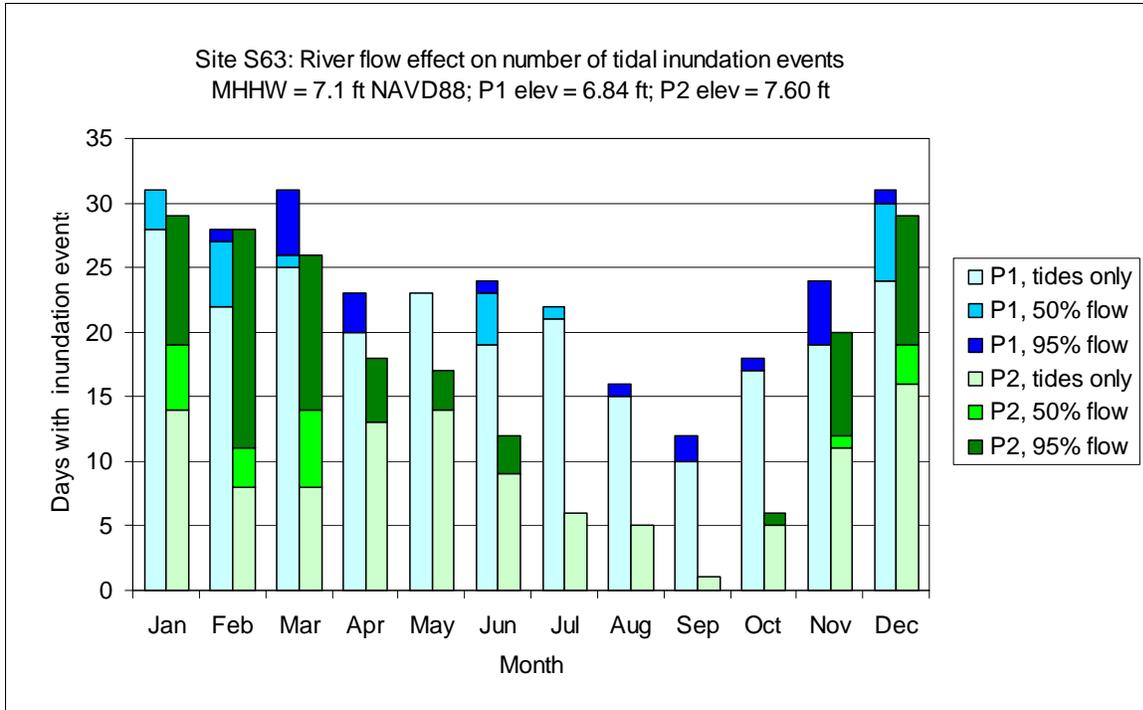


Figure A12. Reference site S63: Effect of river flows on tidal inundation frequency. Inundation frequency is shown for three scenarios: “tides only” (modeled using the master station method); “50% flow” (additional inundation from median river flow levels), and 95th flow (additional inundation from river levels in the 95th percentile of historic records). Plot elevations are NAVD88.

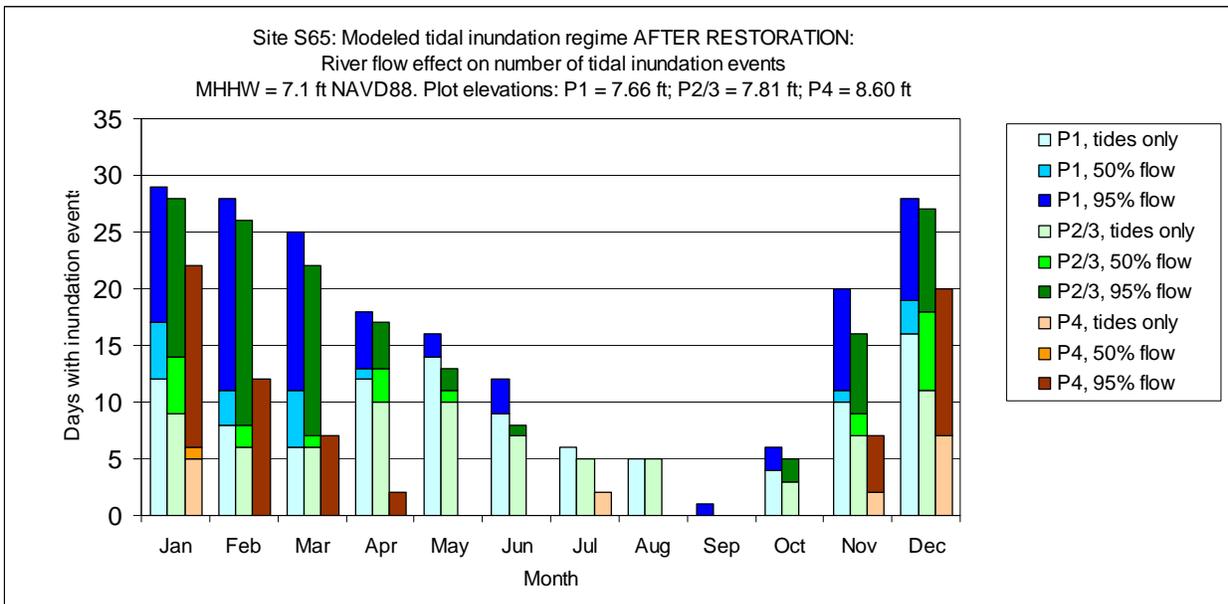


Figure A13. Restoration site S65: Effect of river flows on tidal inundation frequency after implementation of restoration. Inundation frequency is shown for three scenarios: “tides only” (modeled using the master station method); “50% flow” (additional inundation from median river flow levels), and 95th flow (additional inundation from river levels in the 95th percentile of historic records). Plot elevations are NAVD88.

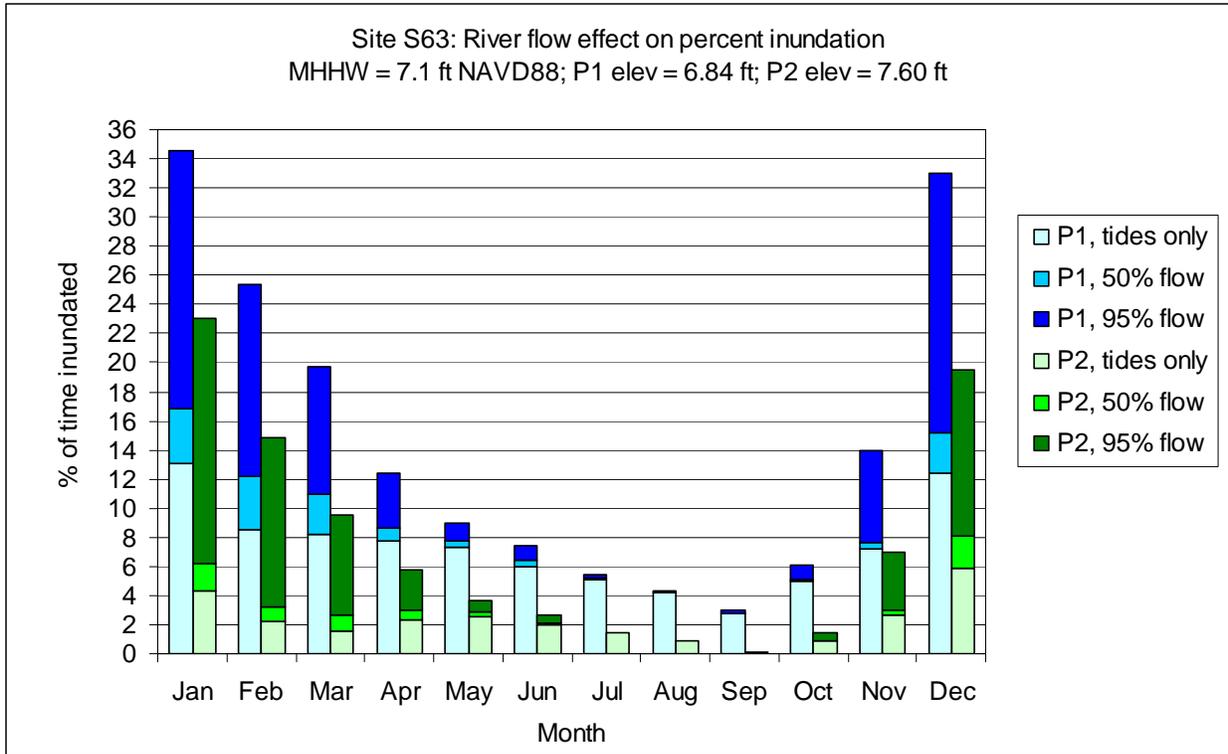


Figure A14. Reference site S63: Effect of river flows on percent inundation. Percent inundation is shown for three scenarios: “tides only” (modeled using the master station method); “50% flow” (additional inundation from median river flow levels), and 95th flow (additional inundation from river levels in the 95th percentile of historic records). Plot elevations are NAVD88.

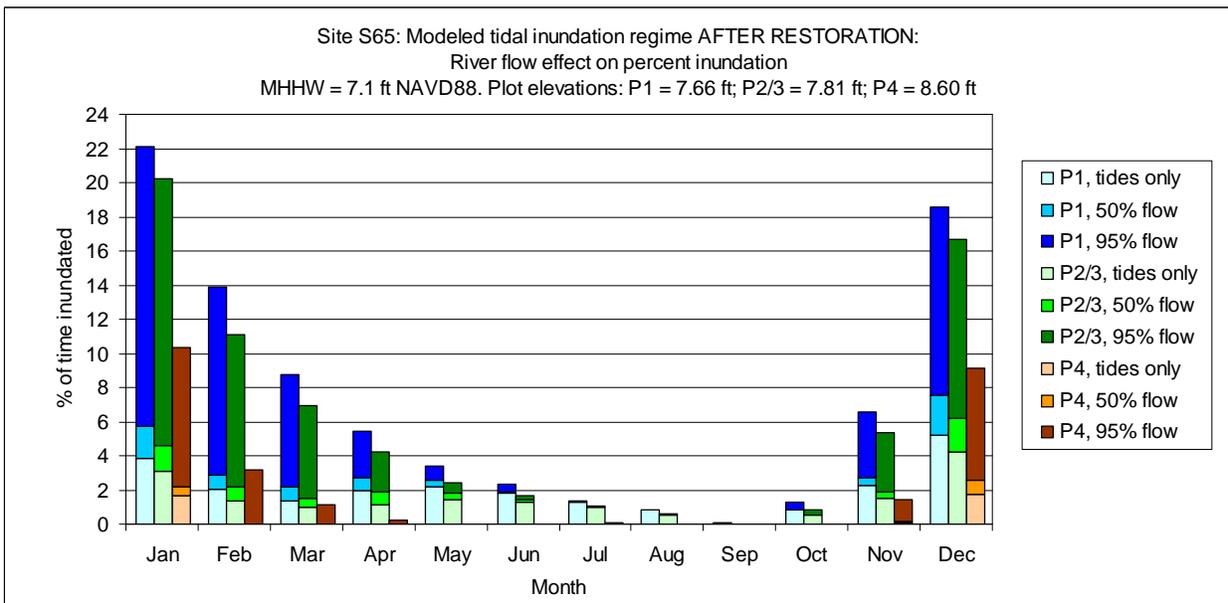


Figure A15. Restoration site S65: Effect of river flows on percent inundation after implementation of restoration. Percent of time inundated is shown for three scenarios: “tides only” (modeled using the master station method); “50% flow” (additional inundation from median river flow levels), and 95th flow (additional inundation from river levels in the 95th percentile of historic records). Plot elevations are NAVD88.

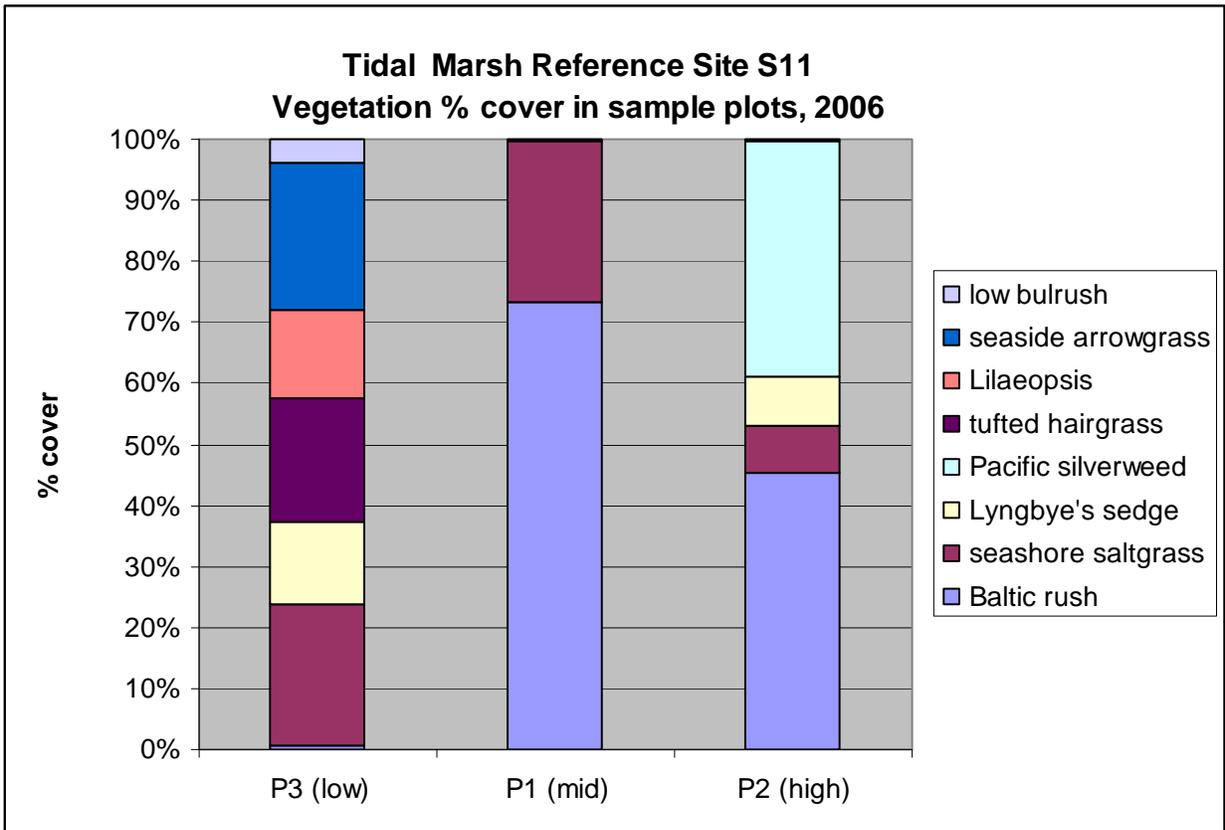


Figure A16. Tidal Marsh Reference site S11 (Cox Island): Plant community composition in sample plots, 2006. All species over 2% cover are shown.

Figure A16 shows the same data as Tables 11 and 12 in graphic form. Bar charts of this type are well suited to illustration of changes in vegetation over time. (Figure 7 provides an example from site S65.) In the future, this chart can be modified to illustrate changes in composition of the plant community at Cox Island (site S11).

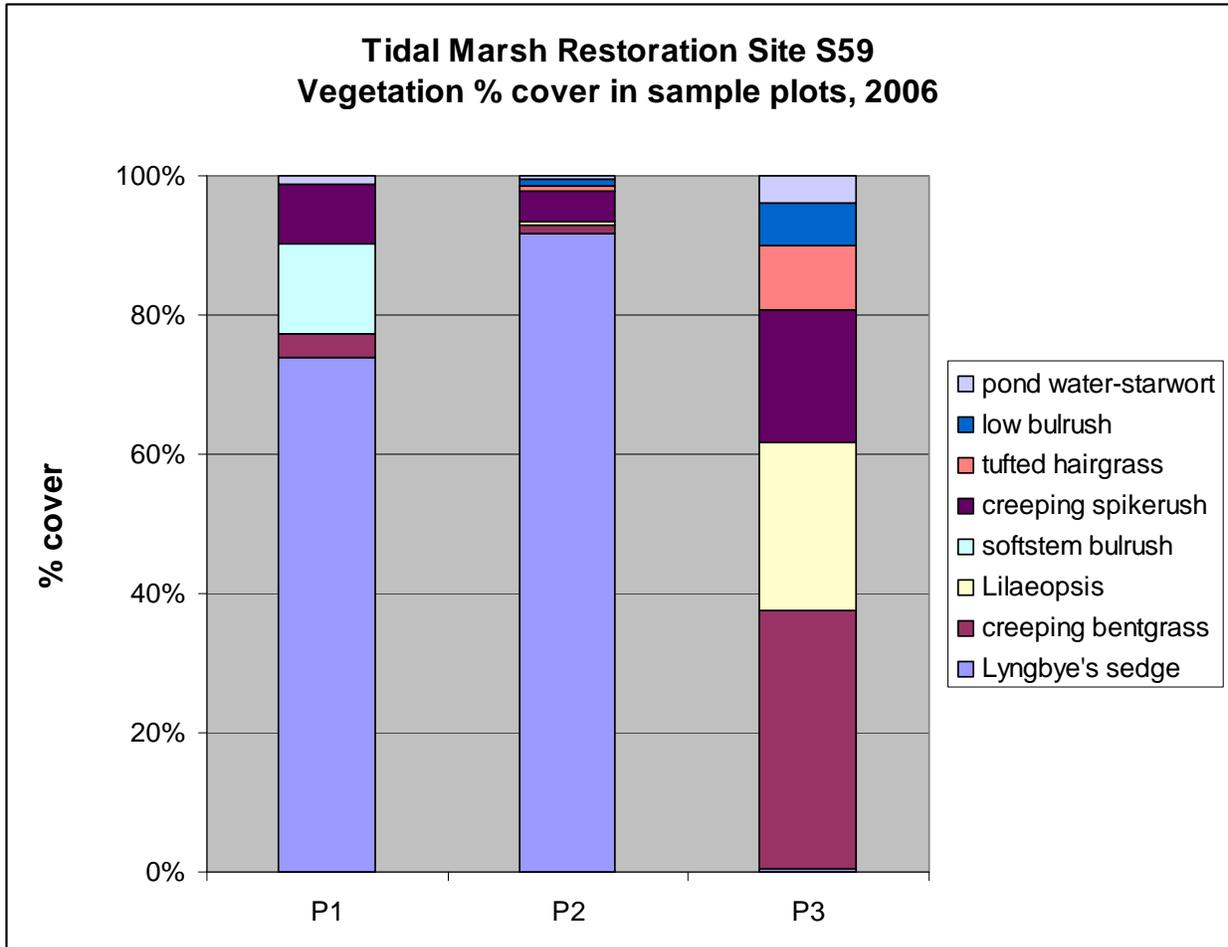


Figure A17. Tidal Marsh Restoration site S59: Plant community composition in sample plots, 2006. All species over 2% cover are shown.

Figure A17 shows the same data as Table 11 in graphic form. Bar charts of this type are well suited to illustration of changes in vegetation over time. (Figure 7 provides an example from site S65.) In the future, this chart can be modified to illustrate changes in composition of the plant community at site S59.

**Tidal Swamp Reference Site S63
Vegetation % cover in sample plots, 2006**

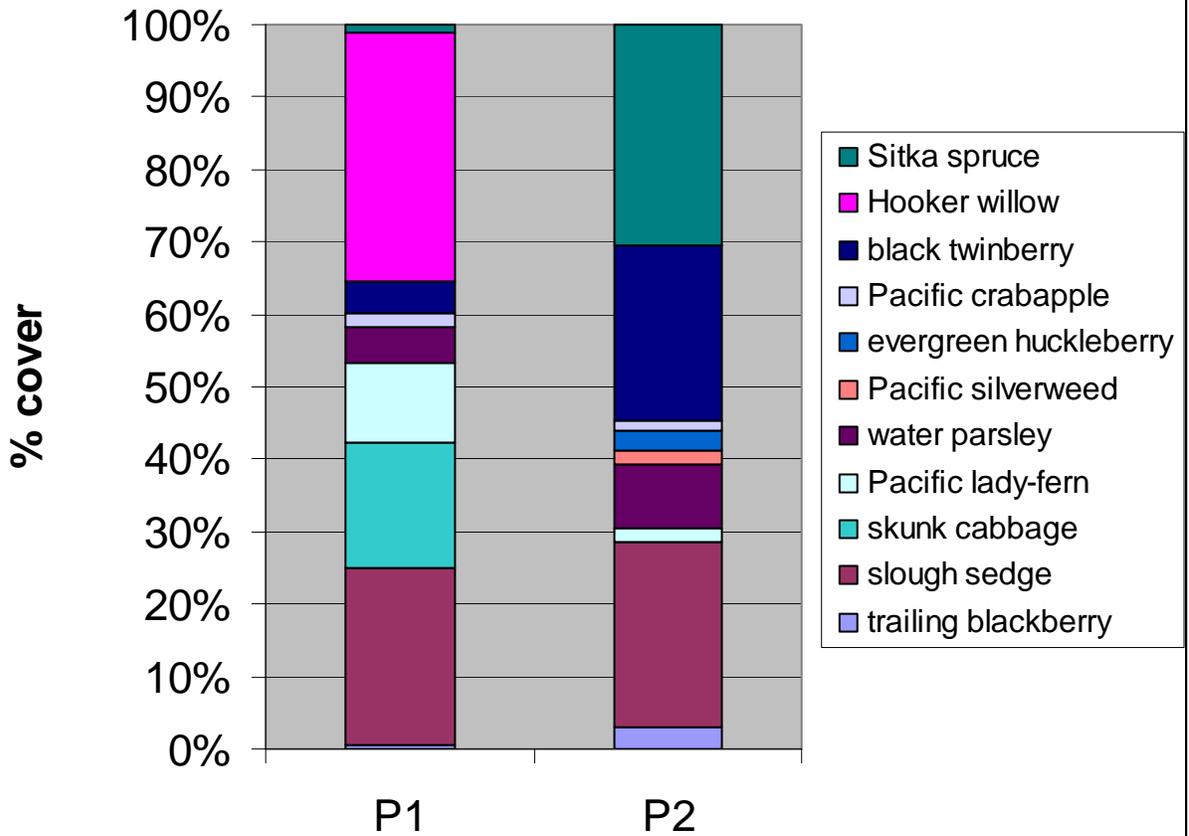


Figure A18. Tidal Swamp Reference site S63: Plant community composition in sample plots, 2006. All species over 2% cover are shown.

Figure A18 shows the same data as Table 13 in graphic form. Bar charts of this type are well suited to illustration of changes in vegetation over time. (Figure 7 provides an example from site S65.) In the future, this chart can be modified to illustrate changes in composition of the plant community at site S63.

Tidal Swamp Reference Site Y28 Vegetation % cover in sample plots, 2006

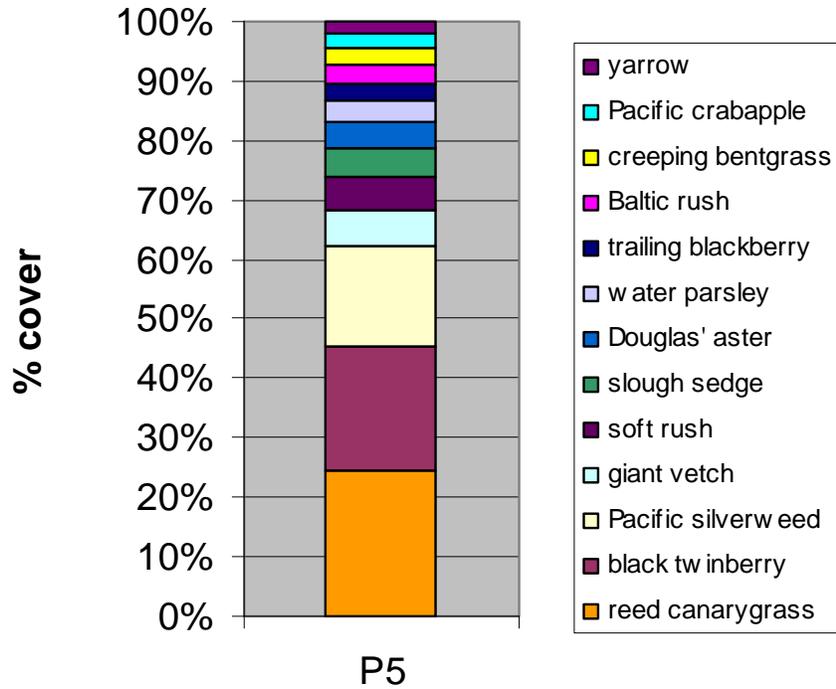


Figure A19. Tidal Swamp Reference Site Y28: Plant community composition in sample plots, 2006. All species over 2% cover are shown.

Figure A19 shows the same data as Table 13 in graphic form. Bar charts of this type are well suited to illustration of changes in vegetation over time. (Figure 7 provides an example from site S65.) In the future, this chart can be modified to illustrate changes in composition of the plant community at Site Y28.

Appendix 3. Photodocumentation at S65 Tidal Swamp Restoration

Please contact Laura Brophy (541-752-7671, Laura@GreenPointConsulting.com) for permission to use photos. These photographs are excerpted from the full photodocumentation provided in Brophy (2008).



Site S65, Photo Point 1B:
View of pasture, looking NE from dike breach.

October 2006 (pre-restoration)



August 2007 (Immediately after restoration earthmoving)



July 2008 (Year 1 post-restoration). White vexar tubes around woody plantings are visible.



Site S65, Photo Point 5:
View south along length of pasture,
from north end of pasture.

October 2006 (pre-restoration)



**August 2007 (Immediately after
mowing, preparatory to
restoration earthmoving)**



**July 2008
(Year 1 post-restoration). White
vexar tubes around woody
plantings are visible.**

Appendix 4. General site photos

Please contact Laura Brophy (541-752-7671, Laura@GreenPointConsulting.com) for permission to use photos.



Photo A1. September 10, 2007: Setting of site S65 on the North Fork Siuslaw River (east-facing view). Photo courtesy of ODOT Photo and Video Services.



Photo A2. September 10, 2007: South-facing aerial view of site S65 immediately after restoration earthmoving (but before woody plantings had been installed). Photo courtesy of ODOT Photo and Video Services.



Photo A3. August 14, 2007: Excavation of pilot channel at site S65. Jeffrey Jones measures channel depth while Nathan Large operates the excavator. Photo by Laura Brophy.



Photo A4. August 14, 2007: Rising tide fills the dike breach at site S65. Photo by Laura Brophy.



Photo A5. September 27, 2007: Spring high tide fills the pilot channel and dike breach area. Photo by Laura Brophy.



Photo A6. March 17, 2008: Site S65 north-facing view of dike breach and former pasture; partial dike removal and extensive shrub and tree plantings can be seen (white Vexar tubes). Photo by Laura Brophy.



Photo A7. August 3, 2006: Student volunteer Sam Waterhouse stands in tidal channel in Y28 spruce swamp (low tide) Photo by Laura Brophy.



Photo A8. June 20, 2006: Sitka spruce swamp, site S63 just north of Plot 2. Dense cover of black twinberry fills the foreground. Photo by Laura Brophy.



Photo A9. January 4, 2007: Willow scrub-shrub tidal wetland, site S63 Plot 1, during wintertime high tide. Inundation depth is about 1 ft. Photo by Laura Brophy.



Photo A10. February 20, 2006: Laura Brophy conducts initial site reconnaissance in a cat-tail opening in willow scrub-shrub tidal wetland, site S63 (north of Plot 1). Photo by Jeff Jones.



Photo A11. May 31, 2006: North Fork Siuslaw River in brackish Sitka spruce tidal swamp zone. Photo by Laura Brophy.



Photo A12. January 4, 2007: Diked pastures on the North Fork Siuslaw River, winter high tide during a high river flow event. Pastures are completely flooded; only the tops of dikes are above water. Photo by Laura Brophy.



Photo A13. January 4, 2007: Cattle move to high ground in flooded pastures on the North Fork Siuslaw River during a winter high river flow event. Photo by Laura Brophy.



Photo A14. September 6, 2007: Northeast-facing aerial view of North Fork Siuslaw River study sites (S59, S63 and S65). Photo by Laura Brophy, aerial flight courtesy of ODOT Photo and Video Services.



Photo A15. September 6, 2007: East-facing aerial view of site S59. Photo courtesy of ODOT Photo and Video Services.



Photo A16. September 6, 2007: South-facing aerial view of Cox Island (site S11). Photo courtesy of ODOT Photo and Video Services.



Photo A17. July 1, 2006: Diverse high marsh flora on high natural levee at Cox Island. Photo by Laura Brophy.

Appendix 5. Quality Assurance Project Plan

Note: The final QAPP consists of this Appendix and the modifications in **Appendix 6, Modifications to QAPP 6/22/07**.

Quality Assurance Project Plan
For
Siuslaw Basin Targeted Watershed Project:
Goal 4- Estuary Restoration Monitoring

Prepared by:

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541-997-9360

Prepared for:

Alan Henning
USEPA
1102 Lincoln, Suite 210
Eugene, OR 97405

Date: March 1, 2006

Approvals:

Laura Brophy, Project Manager, Estuary Ecologist/ March 5, 2006
Green Point Consulting, Corvallis, OR

Thomas C. Dewberry , Project QA Manager,/ March 5, 2006
Ecotrust

Alan Henning, USEPA Project Manager, Environmental Protection Specialist/

Roy Araki, QA Officer, USEPA , Regional Quality Assurance Manager/

Table of Contents:

Distribution List.....Page 3

Chapter 1: Group A

A4. Project/Task Organization.....Page 4

A5. Problem Definition/Background.....Page 5

A6. Project/Task Description.....Page 5

A7. Quality Objectives and Criteria.....Page 6

A8. Special Training/ Certification.....Page 6

A9. Documents and Records.....Page 6

B1. Sampling Process Design.....Page 6

B2. Sampling Methods.....Page 7

B3. Sample Handling and Custody.....Page 12

B4. Analytical Methods.....Page 13

B5. Quality Control.....Page 13

B6. Instrument/Equipment testing, Inspection, and Maintenance.....Page 13

B7. Instrument/Equipment Calibration and Frequency.....Page 14

B8. Inspection/Acceptance of Supplies and Consumables.....Page 14

B9. Non-direct Measurements.....Page 14

B10. Data Management.....Page 14

C1, Assessment and Response Actions.....Page 14

C2. Reports to Management.....Page 15

D1. Data Review, Verification, Validation.....Page 15

D2. Verification and Validation Methods.....Page 15

D3. Reconciliation and User Requirements.....Page 16
Appendix #1.....Separate Attachment

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Davies, Brent. Siuslaw Targeted Watershed Project Coordinator, Ecotrust, 721 NW Ninth Ave, Suite 200, Portland, OR 97209.

A4- Project/Task Organization:

The Siuslaw Targeted Watershed project consists of five separate parts (See Appendix I). The overall project coordinator is Brent Davies, Ecotrust. This Quality Assurance Plan only addresses the fourth part of the project, designing and conducting an effectiveness monitoring program at tidal marsh restoration sites. Monitoring elements include: tidal inundation regime, ground-water fluctuation, plant community composition, and soil and chemical characteristics. This plan only addresses the quality assurance for the effectiveness monitoring of the tidal wetland restoration and reference sites.

The primary investigator for goal four is Laura Brophy. She has a M.S. degree and 26 years of research experience in restoration ecology. In 2003, she was selected to develop a statewide protocol for tidal wetland assessment for the Oregon Watershed Enhancement Board's Oregon Watershed Assessment Manual. All of the work will be completed by Laura Brophy, Green Point Consulting.

Thomas C. Dewberry, Ecotrust, will be the Quality Assurance Manager for goal four of the project. He is responsible for ensuring that the elements of the Quality Assurance plan are met.

The Siuslaw Watershed Geographer, Eric Sproles, will provide GIS support for this project. He will export the data into the appropriate file management software for use by the primary local partners.

A5- Problem Definition/ Background

All estuary restoration sites should include a basic effectiveness monitoring program. Ideally, effectiveness monitoring evaluates the success of the restoration by measuring indicators of wetland functions. These results are best compared to one or more reference sites.

A6. Project/ Task Summary

General goals for monitoring program

- Use standard sampling protocols to facilitate data exchange between this and other Pacific Northwest tidal wetland restoration projects.
- Focus on methods and parameters prioritized in national and regional monitoring guidance (Thayer et al 2005, Zedler 2001 and Simenstad 1991).
- Use protocols and analytical methods that will facilitate detection of change over time at the individual site scale in future monitoring efforts.
- Use protocols suitable for future monitoring by volunteers and Watershed Council staff.
- Maintain technical liaison between this project and other Oregon tidal wetland restoration practitioners, including U.S. Fish and Wildlife Service, U.S. Forest Service, and South Slough National Estuarine Research Reserve, to ensure data compatibility and scientific interchange.

A7. Quality Objectives

Ensure that the proper measurements are collected for effectiveness monitoring of the estuary restoration projects. Also, ensure that the measurements fall within the range of accepted accuracy and precision to yield meaningful evaluation of the success of the restoration efforts.

A8. Special Training/ Certification

All data will be collected by Laura Brophy, who is recognized as a competent restoration ecologist.

A9. Documents and Records

All field notes will be collected and maintained by Laura Brophy, Green Point

Consulting. A separate copy of the field notes will be made and kept at a second location.

The field notes will be transferred into a standard data base. All data will be checked and verified by a second party for accuracy of transcription into the data base. This information will ultimately be entered into the STORET system as well as maintained by the Siuslaw Watershed Council for a period of 25 years.

B1: Sampling Process Design

This monitoring program will sample at both restoration and reference sites. Reference sites will be selected following nationwide standards (Merkey 2005, Rice et al. 2005, Diefenderfer et al. 2003). At each study site, sampling design will follow national guidelines (Thayer et al. 2005) and regional standard sampling guidance (Zedler 2001, Simenstad et al. 1991). The specific sampling design will be based on an EPA-recommended bioassessment method (U.S. EPA 2006, Peet et al. 1998). Within study sites, sampling will be stratified to minimize variability due to major environmental gradients including elevation, soils, and tidal influence. Sampling will use permanent plots incorporating a flexible, modular layout with nested sampling to allow data analysis at multiple scales – essential for complex habitats with a wide range of individual organism sizes. Replicated permanent plots, 20 by 50m in size, will be established within relatively homogeneous and representative areas of major plant communities, oriented so as to minimize the environmental heterogeneity within the plot. Each permanent plot will consist of ten modules, each 10 m by 10 m. Aggregate data will be collected within the entire permanent plot, and a subset of the modules will be intensively sampled. Permanent plot

size and number of modules may be adjusted to achieve homogeneity within the plot. Details of sampling methods are described for individual attributes below.

B2. Sampling Methods

General goals for methods

- This project will use methods suitable for restoration practitioners with diverse backgrounds/skills, from grassroots groups to academic researchers.
- Standard sampling protocols will be used to maximize national and regional data comparability.
- Measured attributes will include those prioritized in NOAA/NCCOS “Science-based Restoration Monitoring of Coastal Habitats: Volume 2” (Thayer et al. 2005), Zedler (2001) and Simenstad (1991).
- Protocols and analytical methods will facilitate detection of change over time at the individual site scale in future monitoring efforts, to leverage study results.
- Standard QA/QC protocols will be followed to ensure validity of results.

Monitoring element: Tidal inundation regime

- **Goal:** Determine depth and duration of tidal inundation for major plant communities during all seasons
- **General methods:** Electronic water level logger (recording level gauge)
- **Sampling design:** Single level gauge located near mouth of tidal channel, combined with elevation survey using laser level
- **Measurement parameters:** Water depth (level gauge)
- **Sampling duration:** At least three full tidal cycles during spring and neap tide cycles

- **Sampling frequency:** Four separate recording sessions, one per season (spring, summer, fall, winter)
- **Reference:** Zedler 2001

Monitoring element: Groundwater fluctuation

- **Goal:** Determine depth and seasonal variability in water table depth within major plant communities in scrub-shrub and forested tidal wetland sites, where groundwater fluctuation is a primary habitat driver and responds to both tidal fluctuation and freshwater inputs (surface flows, precipitation)
- **General methods:** Electronic water level logger (recording level gauge) in shallow observation well to detect tidal influence on groundwater levels; manual water level check at weekly or biweekly intervals to determine overall water table dynamics.
- **Sampling design:** Observation well located in center of vegetation transect or permanent monitoring plot
- **Measurement parameters:** Water depth (level gauge)
- **Sampling duration:** Electronic logger: 1 month logging sessions during winter high flows and summer low flows. Manual level check: May through September 2006; February through September 2007.
- **Sampling frequency:** Electronic logger: 15 minute logging interval. Manual level check: Weekly/biweekly sampling.
- **Reference:** U.S. Army Corps of Engineers 2005

Monitoring element: Vegetation

- **Goal:** Characterize species composition of major plant communities. Use methods and plant community classification compatible with the National Vegetation Classification Standard (Anderson et al. 1998, Grossman et al. 1998) and regional wetland classification (Kagan et al 2005).
- **General methods:** Field observation and measurement of plant community composition
- **Sampling design:** Stratified random sampling. Permanent plots and transects will be established within environmental strata determined by visual observation of plant communities, elevation, hydrology, tidal influence and salinity.

- **Sampling units:**

Herbaceous communities: Cover quadrats (1 sq m), locations randomized along the central axis of 20m by 50m permanent plots.

Forested and scrub-shrub communities: Nested quadrats within 20m by 50m permanent plots. Permanent plots established within homogeneous communities (environmental strata). Each permanent plot consists of 8 modules 10X10m; four of the ten are sampled more intensively (“focus modules”). Total number of modules and number of focus modules may be adjusted based on size of site and stratum. See US EPA 2006, Peet 1998 for detailed methods.

- **Measurement parameters:**

Herbaceous species: Percent cover by visual estimate, presence/absence (for calculation of percent frequency)

Woody species: Percent cover by visual estimate within all modules; stem counts and basal area for focus modules. Stem counts will consist of stem tallies by species within diameter

classes (dbh), individual dbh measurements for stems >40cm dbh, and seedling counts for trees <1m height.

- **Derived values:** Percent frequency by plot size, species richness, diversity index; seedling/stem density and basal area for woody species

- **References:**

Stratified random sampling: Simenstad et al. 1991, U.S. EPA 2006, Peet et al. 1998

Vegetation sampling: U.S. EPA 2006, Peet et al. 1998

Monitoring element: Soil physical and chemical characteristics

- **Goal:** Characterize critical soil variables within major plant communities, to assist restoration planning and evaluation of restoration trajectory.
- **Sampling design:** Stratified random sampling. Subsamples will be collected at random locations within the permanent vegetation plots, allowing characterization of soils within the monitored plant communities. Subsamples will be extracted from the top 30cm of soil (fine root zone for most vascular species), bulked in the field, and a portion extracted for analysis in the laboratory. Grab samples for porewater salinity will be taken from the top 30cm of soil.
- **Sampling units:** Bulk sample for % organic matter, textural analysis, pH and electrical conductivity; grab sample for porewater salinity extracted from surface soil.
- **Measurement parameters:** Field measurement: salinity from porewater grab sample using refractometer or small-volume handheld salinity/conductivity meter. Laboratory analysis (conducted by OSU Central Analytical Laboratory): Percent organic matter by loss on ignition (alternatively, % carbon may be determined by LECO analyzer, and converted to %

OM); grain size distribution (textural analysis) by hydrometer; pH; electrical conductivity of soil solution.

- **References:** USDA-NRCS National Soil Survey Center 1996, Dane and Topp 2002, Sparks 1996, Zedler 2001.

Landscape setting

Landscape setting parameters collected for each site will include:

- Site topography (by spot elevation survey at both ends of each vegetation transect and permanent plot, channel banks, and other strategic locations on site)
- Habitat interspersions (by aerial photograph interpretation and existing orthophotography)
- Overall slope of site (by spot elevation survey at channel bank and upland edge)
- Aspect
- Geomorphic setting (topographic position, landform type)

Statistical methods

For each of the sampled parameters, the appropriate statistical tests will be selected from the following methods:

- Summary statistics (mean, range, variance) will be calculated for all measured parameters. Means at restoration and reference sites will be compared using t-tests where appropriate.
- Recommendations will be provided for future analyses, such as analysis of variance and means comparisons (both parametric and nonparametric depending on data characteristics) for detection of change over time.
- **References:** Green 1979, Snedecor and Cochran 1989

B3. Sample Handling and Custody

All samples collected and transported to the laboratory will be in the custody of Laura Brophy. Soil samples will be analyzed at the Oregon State University Central Analytical Laboratory, whose existing QA/QC protocols are designed to prevent sample identification error and sample loss.

B4. Analytical Methods

Laboratory analysis of the soil physical and chemical characteristics are as follows: Percent organic matter by loss on ignition (alternatively, % carbon may be determined by LECO analyzer, and converted to %OM); grain size distribution (textural analysis) by hydrometer; pH; electrical conductivity of soil solution.

Reference: Dane and Topp 2002, Sparks 1996

B5. Quality Control

Water level logging instrumentation will be selected from widely tested commercial packages, including Onset, Global, or Greenspan Analytical water level loggers (Onset 2006, Global 2006, Tyco Environmental Systems 2006). Salinity will be tested using a handheld refractometer or low-volume handheld salinity/conductivity meter with range 0-100mS/cm. Selected instrumentation will meet the following accuracy and precision standards: Water level, 1 inch (2.5 cm); salinity, 1 ppt (approx. 1mS/cm conductivity). Laboratory soils analysis will follow Oregon State University Central Analytical Laboratory's internal QA/QC procedures.

B6. Instrument/ Equipment Testing, Inspection, and Maintenance

Instrumentation will be tested and maintained following manufacturer's recommendations.

B7. Instrument/Equipment Calibration and Frequency

Salinity testing equipment will be calibrated using salinity calibration standards immediately prior to each field sampling session. Water level instrumentation will be calibrated at deployment following manufacturer's recommendations.

B8. Inspection/ Acceptability of Supplies and Consumables

Salinity calibration standards will be purchased in airtight single-use packets to ensure freshness.

B9- Non-direct Measures

Not applicable.

B10. Data Management

Data will be managed directly by Green Point Consulting. After each sampling trip, data will be copied and stored in a separate location. Data entered into electronic format will be backed up daily to an external hard drive and weekly to an offsite location.

C1. Assessments and Response Actions

The project quality assurance manager, Thomas Dewberry, is responsible for quality assurance of this part of the Siuslaw Targeted Watershed Project. During the survey period at a time or times of his discretion, he will ensure that the QA plan is being implemented as prescribed.

C2. Reports to Management

The primary investigator will provide the project manager, USEPA project manager, and the Siuslaw watershed Council coordinator with timely quarterly and annual reports of the progress of the project. These reports will include summaries of the field measurements, analysis, and conclusions of the effectiveness monitoring.

D1. Data Review, Verification, and Validation

Electronic data transcribed from field datasheets will be verified by a third party (Siuslaw Watershed Council staff). Green Point Consulting will check data for outliers and overall data integrity.

D2. Verification and Validation Methods

Green Point Consulting will transfer copies of field data forms and transcribed electronic data to the Siuslaw Watershed Council for verification. SWC will check electronic databases line by line for correct transcription and return annotated databases to Green Point Consulting. Green Point Consulting will then validate the data, checking for outliers and data integrity by cross-referencing electronic data with field data forms. The final verified and validated database copies will be returned to the Siuslaw Watershed Council and will be stored in STORET data storage.

D3. Reconciliation with User Requirements

The Siuslaw Watershed Council will receive the survey information in a standard data base and they will receive the maps in GIS format. For the USEPA the effectiveness monitoring information will be entered into STORET data storage.

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Appendix 6. Modifications to Quality Assurance Plan: June 22, 2007

June 22, 2007: Modifications to Quality Assurance Plan

Siuslaw Basin Targeted Watershed Project: Goal 4: Estuary Restoration Monitoring

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Several modifications to the QAPP are requested below. The need for these changes became apparent through two processes: 1) Better methods have become available as we have developed collaborative relationships in the estuary; (2) Field experience during 2006 showed that modifications would achieve better results than the original plan.

Changes are referenced to the section and page in the approved QAPP (Revision No. 2, dated June 6, 2006).

1) Monitoring element: Tidal inundation regime (page 10)

Rationale for revision: Substitute full-season gauging and high-accuracy modeling of long-term tidal inundation regime for short-term gauging. Through development of a collaborative relationship with Dr. Ray Weldon at the University of Oregon, we have greatly improved our monitoring of tidal inundation regime at the Siuslaw River Estuary sites.

Text revisions: Remove sections entitled “Sampling duration” and “Sampling frequency” and substitute the following paragraph:

Sampling duration and frequency: Three months of high-accuracy tide gauge data were collected during summer 2006 by Dr. Ray Weldon, University of Oregon. (Dr. Weldon is an expert in analyzing tide and land surface levels on the west coast of the U.S. and abroad.) Weldon’s gauges were located near site S63 on the North Fork Siuslaw River; and at Cushman, Tiernan and Mapleton on the mainstem. Dr. Weldon’s research team is currently modeling tidal inundation regime at each gauge location, incorporating the influence of river flows. (River flows are a strong influence on inundation regimes in Oregon estuaries, but are not addressed in standard tide tables and NOAA predictions.) We will use Weldon’s data and methods to calculate inundation regimes for the project sites.

2) Monitoring element: Groundwater fluctuation (page 11)

Rationale for revision: As we proceeded with site analysis during summer of 2006, we learned that we needed wintertime observations and preliminary analysis of tidal inundation regime (“TIR”) to decide which sites required groundwater monitoring. TIR information was needed because we only planned to monitor groundwater at those sites where nontidal groundwater hydrology would be a “controlling factor” – that is, it would exert a strong influence on plant communities and other site biota and on site functions. Sites where groundwater is a strong controlling factor are those where tidal inundation occurs mainly in winter and seldom in summer (most likely, forested and scrub-shrub tidal wetlands in the upper estuary). At other sites

(those with year-round tidal inundation), nontidal hydrology is not a controlling factor and groundwater measurement is not needed.

In addition, the first winter's observations at our tidal swamp sites showed that groundwater monitoring is not needed or even possible at this project's forested and scrub-shrub tidal sites during winter, due to frequent overtopping of the groundwater wells by tidal flows. These observations also demonstrated that groundwater monitoring is not needed at these sites during winter, because frequent tidal inundation maintains high water tables in winter.

Text revisions: Delete the paragraphs "Sampling duration" and "Sampling frequency" and substitute the following paragraph:

Sampling duration and frequency: Manual groundwater level checks will be conducted weekly or biweekly during spring and summer 2007, after completion of 2006 winter flood observations and preliminary modeling of tidal inundation regime. Time between groundwater level measurements at paired restoration and reference sites will not exceed 24 hours, allowing valid comparison of results. Electronic loggers recording groundwater levels at 15 minute intervals will be deployed for at least 1 spring tide cycle during summer 2007 to determine whether tidal fluctuation affects groundwater levels.

Monitoring element: Vegetation (page 12)

Rationale for revision: The sampling method described in the original QAPP is flexible and allows modification of sampling unit size and number. Field experience during the first day of 2006 sampling in forested and scrub-shrub wetlands indicated that improved data would be obtained by reducing module size, sampling a larger number of modules, and conducting complete stem counts within each module. These modifications were driven by the vegetation type (shrub-dominated with few large trees).

In addition, the original QAPP called for seedling counts, a monitoring parameter frequently used in riverine swamps with minimal herbaceous understory. However, it became clear during initial field work that seedling counts would not be logistically possible. At our sites, very dense herbaceous understory vegetation hides seedlings, and it would be extremely time-consuming and destructive to move the layers of herbaceous vegetation aside and search for the few seedlings that may be present. To obtain data more appropriate to our local habitats, we conducted complete counts of all woody stems (including saplings under 1cm) within larger sampling units than originally planned, as described above.

Text revisions:

a) Under "**Sampling units: Forested and scrub-shrub communities**" substitute the following paragraph for the existing one:

Nested quadrats within permanent plots. We will sample 5m by 5m modules within 10m by 50m permanent plots. Six modules will be sampled out of the total of 20 modules; sampled modules will be selected at random. Permanent plot length and number of modules sampled may be adjusted if needed for stratification purposes (i.e., if homogeneous strata are too small for a 50m plot length). See US EPA 2006, Peet 1998 for detailed methods.

b) Under “**Measurement parameters: Woody species**” substitute the following paragraph for the existing one:

Percent cover by visual estimate, stem counts and basal area within each sampled module. Stem counts will consist of stem tallies by species within diameter classes, and individual dbh measurements for stems >40cm dbh.

Monitoring element: Soil physical and chemical characteristics

Rationale for revision: After consultation with our colleagues in the region (regional experts in tidal wetland restoration and monitoring), we determined that field grab sample measurements of porewater salinity probably do not offer adequate accuracy or representativeness for our purposes. The QAPP already included laboratory analysis of electrical conductivity (EC) of the soil solution, which is a better measurement of salinity conditions in the soil; so, we decided to eliminate the porewater grab samples. EC analysis is preferable for two main reasons: 1) Our EC samples are bulked from at least a dozen subsamples across the entire permanent plot, a process that is not possible with porewater grab samples. (Due to the time required for porewater grab samples, only one or two samples per plot are possible.) 2) EC uses a more accurate measuring device (laboratory conductivity probe) rather than the less-accurate refractometer that must be used for field measurement of porewater salinity (due to the small volume of porewater extracted).

Text revisions: In the section “**Sampling design,**” delete the last sentence referring to grab samples for porewater salinity. In the section “**Sampling units,**” delete the last clause of the sentence, which refers to grab samples for porewater salinity. In the section “**Measurement parameters,**” delete the first sentence referring to grab samples for porewater salinity.

Monitoring element: Landscape setting (page 14)

Rationale for revision: During 2006 we established collaborative relationships for this project with the University of Oregon, Oregon State University, Oregon Department of Transportation, and South Slough NERR. Discussions with these colleagues and analysis of tidal inundation regime (“TIR”) at the project sites indicated that with our limited funds for elevation survey, we should focus our efforts on our permanent plots, where we have detailed data on vegetation and soils. Adequate modeling of TIR for other portions would require complete topographic survey, an expensive process that is not funded under this project. (Fortunately, we were able to obtain complete topographic survey data for the tidal swamp restoration site S65 through our collaboration with ODOT.) Under our existing budget, we were able to survey a very limited number of site features (such as the natural levee on Cox Island, site S11), but could not adequately survey the range of channel bank and thalweg elevations or the wider range of site features (such as dikes and marsh plain surfaces) that would be necessary to characterize overall site topography and channel bathymetry.

Text revision: Under “Landscape setting,” change the first bullet point to read “Site topography (by spot elevation survey at both ends of each vegetation transect and permanent plot).” Change

the third bullet point to read “Typical slope of site (by elevation survey of lowest and highest vegetation plots).”