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Lower Columbia River and Estuary Ecosystem Restoration Program Reference Site Study: 2011 Restoration Analysis

FINAL REPORT

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May 2012

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Abstract

The research presented in this report is part of the regional habitat restoration program in the lower Columbia River and estuary (LCRE). As part of this program, we have established a suite of reference sites to help meet the goal of understanding and restoring wetland habitat. The data collected at these reference sites from 2005 through the present were analyzed in this study to meet two primary objectives: 1) to inform restoration planning and design by quantifying the ecological and hydrological conditions necessary for development of wetland plant communities and tidal channel networks and 2) to evaluate the effectiveness of wetland restoration actions in the LCRE by comparing restoration and reference site monitoring data. In this report, we present the results of the analysis of 51 reference wetland sites, focusing on the elevation, sediment, and inundation ranges required by native tidal wetland vegetation. We describe critical factors influencing existing wetland patterns in the LCRE, including the vegetation assemblages present, the elevation ranges at which they occur, and the inundation dynamics that result in their current distribution. Finally, we present how these data can be used to evaluate restoration action effectiveness.

Executive Summary

The Reference Site (RS) study is part of the research, monitoring, and evaluation (RME) effort developed by the Action Agencies (Bonneville Power Administration, U.S. Army Corps of Engineers, Portland District, and U.S. Bureau of Reclamation) in response to Federal Columbia River Power System Biological Opinions. Although the RS study was initiated in 2007, data have been collected at relatively undisturbed reference wetland sites in the lower Columbia River and estuary (LCRE)[1] by the Pacific Northwest National Laboratory (PNNL) and collaborators since 2005. These data on habitat structural metrics were previously summarized to provide baseline characterization of 51 wetlands throughout the estuarine and tidal freshwater portions of the 235-km LCRE; however, further analysis of these data has been limited. Therefore, in 2011, we conducted additional analyses of existing field data previously collected for the Columbia Estuary Ecosystem Restoration Program—including data collected by PNNL and others—to help inform the multi-agency restoration planning and ecosystem management work under way in the LCRE.

The goal of the 2011 RS study reported herein was to help inform the restoration planning and management effort in the LCRE by exploring two guiding questions:

1. What are the ranges of selected environmental factors controlling the establishment and distribution of wetlands in the LCRE, and what vegetation communities are associated with these ranges in different parts of the LCRE?
2. Can structural data from multiple reference sites be used to evaluate restoration action effectiveness in the LCRE and if so, what metrics are most useful to this evaluation?

The general approach of this study was to further analyze existing data from a suite of 51 reference wetlands in conjunction with analysis of available comparable data from 10 restoration projects initiated within the last decade.

Our analysis first develops the basis for the distribution of vegetation characteristic of the region using available ecological and hydrological data. We then use discriminant function analysis of the vegetation data from the least disturbed sites to provide verification for the observed hydro-vegetation zonation. We conclude the analysis of vegetation patterns by providing the elevational ranges of selected plant species and communities for the different hydro-vegetation zones of the LCRE. Finally, we compare reference sites to restoration sites within each of these zones; evaluating several metrics including accretion rates, elevation, temperature, vegetation, and channel morphology.

We summarize the conclusions from the Reference Site study according to two main topics: 1) gradients in the vegetation assemblages relative to hydrodynamics and other factors and 2) the relative similarity of restored sites to reference sites.

[1] The term “lower Columbia River and Estuary” (LCRE) and the term “estuary” are used interchangeably in this document to refer to the tidal extent of the lower Columbia River; from the mouth to the Bonneville Lock and Dam at rkm 235.

Hydro-Vegetation Zones

Shallow-water vegetation assemblages show distinct differences along the gradient between the mouth of the river and the upstream end of the estuary at Bonneville Lock and Dam. There are three zones based on species richness; the central region (rkm 50 to rkm 150) has the greatest number of species, and the upper and lower ends of the estuary have lower numbers of species. These three species richness zones can be characterized hydrodynamically as tidal-dominated, mixed tidal and river-dominated, and river-dominated, moving from the mouth of the Columbia River to Bonneville Dam.

We hypothesize that fewer vegetation species are physiologically adapted to the extreme inundation in the upper end of the estuary, and, likewise, few are adapted to the tidal variability and salinity in the lower estuary. The fact that the mixed zone contains the greatest number of species suggests that the natural ecological disturbance regime may be lower there, and there may be a larger species pool adapted for these conditions in this zone. This intermediate disturbance hypothesis has been used in many ecosystems to describe the conditions that result in higher species diversity.

Further examination of the hydrologic gradient revealed that the estuary can be divided further into five zones, driven primarily by salinity intrusion at the lower end and stronger fluvial flooding influence at the upper end. The breaks for these zones occur at approximately rkm 40, 104, 136, and 181. These breaks are preliminary and should be refined with additional data in areas of sparse sites and with other hydrologic analyses currently under way.

The five hydro-vegetation zones developed from this analysis provide a means of determining the ranges of controlling factors (e.g., elevation, hydrology, accretion rates) at reference sites within each zone. These ranges can then be used to inform restoration planning for sites within each zone. Further, the zones provide a means of comparing restoration sites to relevant reference sites that have similar factors controlling their habitat structure, as discussed below.

The elevation range for the major habitat types (e.g., emergent, shrub, or forested wetland) within a zone is small (i.e., < 2 m), which strongly suggests that elevation and hydrodynamics must be carefully considered in 1) the design of wetland restoration sites, 2) the analysis of differences between sites, and 3) the trajectories and rate of development of restored sites.

With the results from this analysis, the elevation and possibly the growing season inundation (as measured by the sum exceedance value (SEV)) can be used to predict species presence at sites within the same hydro-vegetation zone. For example, the invasive species reed canary-grass (*Phalaris arundinacea*), covered the widest range in elevation of any species. In general, these data on elevations of vegetation species should help in planning restoration actions to maximize native species and minimize the invasion of reed canary-grass into new sites.

Relative Similarity of Restored to Reference Sites

In this section, we summarize the findings from the restoration and reference site comparison then also provide a judgment of the usefulness of each metric as a restoration performance measure.

Sediment Accretion. Most restored sites showed initiation of the process of sedimentation. Accretion indicates that the sites are behaving as sinks of sediment and probably organic matter—two processes indicative of wetland systems. Accretion rates tended to be greater in restored sites as compared to the least-disturbed reference sites.

> *Usefulness of metric*: Sediment accretion is required to build wetland elevations and is easily and cost-effectively measured in the field. This metric provided a valuable means of comparing restoration to reference conditions in the analysis.

Elevation. Elevations of previously diked restored sites were lower than reference sites. Again, this suggests that accretion is needed to restore the sites to the historical vegetation assemblage. The excavated site was more similar to reference elevations than other hydrologically reconnected sites.

> *Usefulness of metric*: This metric can be difficult and expensive to measure in the field but is invaluable to determine the likelihood of a site establishing the target hydrologic patterns and vegetation community. The simple comparison of the average, minimum, and maximum elevations proved a simple means of comparing the site elevations.

Inundation. Natural hydrological connection and dynamics were restored at the two sites where sufficient hydrological data were available. The hydrologic patterns are likely driving the development and function of the restored sites.

> *Usefulness of metric*: Hydrologic data are essential to determining whether a site has the necessary processes for wetland development. The lack of data from restoration sites resulted in few comparisons, however, we feel the analysis of SEV could be a useful means of evaluating the effect of hydrologic patterns on vegetation particularly when the elevation or hydrology are expected to be different from reference conditions (e.g., tide gate installation).

Water Temperature. Water temperature in restored and reference sites typically first exceeded the Washington State Department of Ecology threshold value for juvenile salmon in late spring. In a few cases, the temperature exceedance occurred in reference sites later than at the restoration sites, likely due to proximity to the main channel and local effects of shade. At the few restoration sites where we had data from multiple sensors within a site, patterns were evident relative to the distance from the outlet or the presence or absence of perennial stream inputs. We did not have pre-restoration data on temperatures, but based on data from a few sites collected before reconnection, we believe that water temperature after reconnection probably remained below the threshold longer as compared to pre-reconnection at the sites we studied.

> *Usefulness of metric*: Temperature is a useful metric for evaluating conditions within wetland areas, particularly habitat function for aquatic species. The date of first exceedance of a temperature criterion is a viable method for determining differences between sites and also for evaluating the condition of the habitat provided at a site.

Vegetation Composition. The bivariate analysis showed that the composition of selected species at some restoration sites was tending toward the composition at the reference sites. The probability of occurrence showed that the species composition of the highest-cover species at the restoration sites was not the same as that of the reference sites, although some similar species were present and increasing over time. Invasive species, particularly reed canary-grass, were a problem at all restoration sites.

> *Usefulness of metric*: The bivariate analysis is a useful way to compare the cover and composition of desired species. The analysis is most useful when reed canary-grass is not highly dominant in the reference sites that are used to compare to the restoration site. This species was not included in the bivariate analysis because it is not one that is "desirable" in these systems. However, the species is very dominant and affects the cover of many other species that occur within the same elevation range at both the restoration and some reference sites.
>
> The probability of occurrence analysis was a useful way to look at the most common species at the sites and compare the cover and composition over time and between the restoration and reference sites.

Vegetation Similarity. The vegetation assemblages at nearly all restoration sites had very low similarity to reference site vegetation. Hogan Ranch and the sites planted with shrubs and trees showed the highest similarity. Sites that were historically forested swamps and had been converted to pasture land showed the lowest similarities to their reference sites. Where data were available for multiple years, restoration sites showed a decreasing similarity from the earliest sampling to the most recent. This suggests that the vegetation is changing rapidly from the initial conditions. Based on previous studies, we suspect that similarity between restored sites and their reference sites will increase measurably over time but not for at least another 5–10 years.

This analysis showed there to also be variability between the reference sites, which could be caused by factors such as recent and historical disturbances (e.g., dredged material placement). This variability illustrates the need to evaluate reference site differences and possibly further stratify the reference sites for comparison to restoration sites.

The reference site similarity was also variable between years. Previous PNNL research found similar results and suggests using the long-term average similarity in reference sites to establish a target similarity between the restoration site and reference site. Because most sites were measured in only one year and not always the same year for all reference sites in the zone, temporal variability must be included in determining the target similarity for the restoration sites.

> *Usefulness of metric*: The similarity index is a very useful way to make broad comparisons based on the vegetation cover and composition between sites and over time.

Channel Morphometry. The channel length plotted against channel cross sectional area at the mouth was an effective means of comparing the restoration and reference sites. Of the four restoration sites compared, one appeared to have too small of a channel outlet, one was unnecessarily large, and two were within the same range or at the expected ratio found at the reference sites. We suspect that the restored channels will trend toward reference site dimensions if hydrological connection is unconstrained.

Channel width at the outlet plotted against the channel depth at the outlet confirmed that two of the channels had similar dimensions to the reference channels and two were considerably deeper relative to the width as compared to the reference channels. Interestingly, these two sites were also the ones with the most similar length-to-area ratios, so perhaps the deeper channels are necessary to adequately drain the area at these sites.

> *Usefulness of metric*: Analysis of channel morphometry can be used to determine the similarity of restoration channels to reference channels when other metrics of hydraulic geometry are not available (e.g., catchment area and total channel length). We found that the primary channel length versus cross-sectional area at the mouth may be a useful measure. However, because channels in reference systems are often complex this analysis should be compared to reference sites using the complete channel network to determine if the relationship is valid. The width-to-depth ratio of channel outlet is useful to evaluate whether a restoration channel is similar to reference channels; however, it does not reflect whether these dimensions are appropriate relative to the size of the site.

Overall, our findings provide new information on factors structuring shallow-water vegetated habitats along the entire estuary gradient. The relationships between location, hydrology, and elevation provide valuable potential predictors useful in restoration planning and to evaluate the rates and trajectories of restored sites.

Recommendations

The following recommendations resulting from this study are specific to the methods for future analysis. These are not recommendations for restoration actions. Specific recommendations for data management include the following:

- Standardize data organization and summarizing across data collection efforts in the estuary.
- Develop a continuous dataset for all time-series data.
- Use the U.S. Department of Agriculture plant database for vegetation identification (or identify which field guide is used).
- Record vegetation data using scientific name, rather than common name
- Measure elevation data in North American Vertical Datum of 1988 via local benchmark, then convert to the Columbia River Datum where appropriate (i.e., above rkm 35 in the mainstem; not in tributary sites).
- Compile summarized data into one database or spreadsheet for analysis.

The following recommendations would improve the ability to make comparisons between reference sites and restoration sites in the future:

- The differences between reference sites because of recent and historical disturbances need to be evaluated and possibly stratified further prior to comparison to restoration sites.
- Interannual variability needs to be better quantified at reference sites within the estuary.

- Channels in reference systems are often complex. The analysis conducted here on primary channel length should be compared to one using the complete channel network to determine if the relationship between primary channel length and area at channel outlet is valid.
- Additional monitoring data are needed at restoration sites to better understand if sites are developing toward fully functioning and resilient ecosystems, to inform the adaptive management process, and ultimately improve restoration action effectiveness in the future.

Acknowledgments

Foremost, we wish to thank the Lower Columbia River Estuary Partnership for recognizing the importance of this research and facilitating the work since 2007. Specifically, we thank Scott McEwen, who was instrumental in initiating the project and who provided many helpful ideas in the formative stages. We also appreciate the efforts of Jason Karnezis, whose previous work gathering potential reference site information was the starting point for site selection. Evan Haas also provided support during the field collection years. We are grateful to the sponsoring agency, Bonneville Power Association, for providing the funds to carry out the project. We thank the property owners—Columbia Land Trust, The Nature Conservancy, and the Garvin family—for allowing access and providing information about their beautiful properties. The following agencies were also instrumental in providing access to and information about several reference sites throughout the estuary: Scappoose Bay Watershed Council, Oregon State Parks, Oregon Department of Fish and Wildlife, National Park Service, and the U.S. Fish and Wildlife Service. We appreciate the willingness of restoration practitioners to share their monitoring data. Finally, we could not have completed this project without the people who helped conduct the field work, at times putting in very long hours and enduring arduous conditions. We are very grateful for the hard work and great attitudes of Amanda Bryson, Jimmie Cotton, Dana Field, Julia Ledbetter, Lori Lilly, Keith Marco, Dave Nichols, Micah Russell, Ian Sinks, Kathryn Sobocinski, and Allan Whiting.

Acronyms and Abbreviations

7DADmax	seven-day running average of the daily maximum
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CE	Cumulative Ecosystem Response to Restoration Program
CEERP	Columbia Estuary Ecosystem Restoration Program
CLT	Columbia Land Trust
CRD	Columbia River Datum
CREST	Columbia River Estuary Study Taskforce
EM	emergent marsh
FCRPS	Federal Columbia River Power System
GIS	geographic information system
GPS	Global Positioning System
km	kilometer(s)
LCRE	Lower Columbia River and Estuary
LCEP	Lower Columbia Estuary Partnership
m	meter(s)
MLLW	mean lower low water
NAVD88	North American Vertical Datum of 1988
nMDS	nonmetric multidimensional scaling
NOAA	National Oceanic and Atmospheric Administration
PNNL	Pacific Northwest National Laboratory
rkm	river kilometer
RME	research, monitoring, and evaluation
RS	Reference Site
RTK	real-time kinematic
SAV	submerged aquatic vegetation
SEV	sum exceedance value
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WADOE	Washington State Department of Ecology
WSE	water surface elevation

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1.0 Introduction

The Reference Site (RS) study is part of the research, monitoring, and evaluation (RME) effort developed by the Action Agencies (Bonneville Power Administration [BPA], U.S. Army Corps of Engineers, Portland District [USACE], and U.S. Bureau of Reclamation) in response to Federal Columbia River Power System (FCRPS) Biological Opinions (BiOp) (NMFS 2000, 2004, 2008). A subsequent Supplemental BiOp (NMFS 2010) since the study began has not substantively altered elements of the BiOp directly relevant to the study. The RS study was conducted in the lower Columbia River and estuary[1] (LCRE; Figure 1.1) by the Pacific Northwest National Laboratory (PNNL) under contract with the Lower Columbia Estuary Partnership (LCEP), with funding provided by BPA through the Northwest Power and Conservation Council Columbia Basin Fish and Wildlife Program.

Figure 1.1. Lower Columbia River and estuary.

Although the RS study was initiated in 2007, data have been collected at relatively undisturbed[2] reference wetland sites in the LCRE[3] by PNNL and collaborators since 2005 under the RME effort (Johnson et al. 2008). These data on habitat structural metrics were previously summarized to provide baseline characterization of wetlands throughout the estuarine and tidal freshwater portions of the 235-km LCRE (Borde et al. 2011); however, further analysis of these data has been limited. Therefore, in 2011, we conducted additional analyses of existing field data previously collected for the Columbia Estuary

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[1] The term "lower Columbia River and estuary" (LCRE) and the term "estuary" are used interchangeably in this document to refer to the tidal extent of the lower Columbia River; from the mouth to the Bonneville Lock and Dam at rkm 235.

[2] "Undisturbed" in this context refers to the lack of direct physical disturbances, such as development, diking, recreational activities, or direct hydrological modification. There may have been historical modifications to a site, such as dredged material placement, or alterations to a site due to the changes in overall hydrologic and sedimentary processes in the Columbia River in the past 100 years.

[3] Comprehensive descriptions of the LCRE study area are available in previous reports of this project (Borde et al. 2011) and other documents of the RME program (Johnson et al. 2008).

Ecosystem Restoration Program (CEERP)—including data collected by PNNL and others—to help inform the multi-agency restoration planning and ecosystem management work under way in the LCRE.

1.1 Background

In the science of ecological restoration, a reference site is generally defined as a site with environmental conditions similar to those desired at the restoration site and as little disturbed by human activity as possible. As Downes et al. (2002. p. 122, Box 5.1) wrote, "These locations are often not chosen with a particular impact in mind, but to represent what a water body *could* be, or probably would be, in the absence of human disturbance." The RME plan recommended that a suite of reference sites be monitored as part of action effectiveness research on the LCRE to enable future restoration site progress to be assessed by comparison; several general methods for such analysis have been proposed for the LCRE (Johnson et al. 2008; Diefenderfer et al. 2011). Restoration under the CEERP has to date been focused on tidal freshwater and estuarine wetland habitats including marshes, shrub-dominated wetlands, and forested wetlands. Therefore, reference sites comparable to the restoration objectives for each of these vegetation communities are needed.

The rationale for restoration of these vegetated wetlands for listed salmon encompasses direct habitat access for fish as well as the production and export of macrodetritis, a substantial component of the estuarine food web (Bottom et al. 2005; ISAB 2011). The tidal channels intersecting vegetation in the floodplain also provide habitat for many fish and wildlife species, including juvenile salmon (Bottom et al. 2005), and contribute to overall biodiversity of the ecosystem (Tabor 1976). The structural habitat metrics sampled on the RS study, vegetation composition and species cover, provide an indication of emergent marsh production and the potential for organic matter (i.e., macrodetritus) export. Macrodetritis remains important to juvenile salmon foraging in main-stem LCRE habitats (Maier and Simenstad 2009), although its mass is thought to have decreased by some 82% relative to historical levels in the Columbia River (Sherwood et al. 1990; ISAB 2011) because of the well-documented loss of these types of vegetated wetlands.

The metrics analyzed in this study are outlined in the LCRE restoration monitoring protocols (Roegner et al. 2009; hereafter Protocols) as important for assessments of the structure, condition, and forcing factors of brackish and tidal freshwater wetland habitats. The parameters included in these analyses are vegetation composition and percentage cover, marsh elevation, water surface elevation, channel morphology, substrate characteristics, and accretion rates.

The hydrologic regime is of course a fundamental and determining characteristic of all wetlands (Mitch and Gosselink 2000), and the disruption of this regime by diking, water withdrawals, and dam operations is the driving factor in the loss of shallow-water habitats in the LCRE (Kukulka and Jay 2003a, 2003b). Elevation, hydrology, and substrate are the primary factors that control wetland vegetation composition and productivity (Gilman 1993), and sediment accretion is important for maintaining wetland elevation (Elliot 2004). Thus, baseline information on sediment accretion rates is important for predicting the evolution of a restoration site, particularly because sites being restored in the LCRE have often subsided significantly while diked (Diefenderfer et al. 2008; Borde et al. 2011).

Other parameters are indicators of habitat functions. For instance, the assessment of channel cross sections and channel networks provides information on the potential for fish access or opportunity (Simenstad and Cordell 2000) as well as the pathway for export of prey, organic matter, and nutrients.

Information on channel morphology also supports development of the relationship between cross-sectional dimensions and marsh size, which aids in understanding the channel dimensions characteristic of self-maintaining restored marshes and provides information for restoration project design (Diefenderfer et al. 2009).

Periodic analyses of data on indicators of structural and functional components of the LCRE ecosystem, such as those reported herein, are foundational to the adaptive management program described by Thom et al. (2011). In particular, such analyses contribute greatly to our understanding of expected rates of recovery of wetland ecosystems following hydrologic reconnection actions in this region. They also improve our ability to use principles of ecological succession in restoration design (Shuwen et al. 2001) and to predict the magnitude and characteristic environmental effects of future management actions.

1.2 Goals and Objectives

The goal of the 2011 RS study reported herein was to help inform the restoration planning and management effort in the LCRE by exploring two guiding questions:

1. What are the ranges of selected environmental factors controlling the establishment and distribution of wetlands in the LCRE, and what vegetation communities are associated with these ranges in different parts of the LCRE?
2. Can structural data from multiple reference sites be used to evaluate restoration action effectiveness in the LCRE, and if so, what metrics are most useful to this evaluation?

The general approach of this study was to further analyze existing data from a suite of 51 reference wetlands in conjunction with analysis of available comparable data from restoration projects initiated within the last decade. The data collected from the reference sites provides a baseline characterization from which we may begin to address uncertainties regarding the elevation, soil, and inundation ranges required by native tidal wetland vegetation. Specific objectives of the analyses of data from these reference wetland sites were as follows:

1. to begin to quantify the ecological conditions necessary for development of wetland plant communities and tidal channel networks, a critical step in designing restoration projects (Kentula et al. 1992; Steyer et al. 2003; Thayer et al. 2005)
2. to demonstrate a method for statistically evaluating the effectiveness of restoration actions as described in the RME plan for the LCRE (Johnson et al. 2008).

We understand that other studies have recently begun to evaluate restoration site data in the LCRE (e.g., Johnson et al. 2012, Ennis 2009, Parametrix 2009) and wish to stress that this study is not meant to replace or undermine those efforts. This effort is simply intended to provide a standard, repeatable method that could be applied to compare restoration sites to reference sites as one means of evaluating restoration success.

1.3 Collaboration

This study would not have been possible without the collaboration of multiple individuals and organizations through various research programs and restoration projects. As part of the original RS study, we collaborated with the Cumulative Ecosystem Response to Restoration program and the Ecosystem Monitoring program to maximize the number of sites we were able to include in the study (Borde et al. 2011). For the current analysis phase, we have used data from the reference sites included in the previous phase of the study (43 sites) and additional data from sites that were part of the Ecosystem Monitoring program (6 sites) and the Tidal Freshwater Research program (2 sites). The latter set of sites and resulting data are appropriate inclusions in the current analysis because the additional sites are also relatively undisturbed wetland sites. Restoration site data analyzed for this report were collected by the following organizations using standardized methods as outlined in the Protocols when possible (funding agency provided in parentheses):

- Pacific Northwest National Laboratory (PNNL) (USACE)
- Columbia River Estuary Study Taskforce (CREST) (BPA)
- Columbia Land Trust (CLT) (BPA)
- U.S. Fish and Wildlife Service (USFWS) (USACE)
- Scappoose Bay Watershed Council (BPA)
- Parametrix (BPA).

1.4 Report Organization

In Section 2, we outline the methods used to analyze the data from the reference sites and the methods employed to compare these results to restoration site data. The results are presented and discussed in Section 3. First, we describe the hydrologic and vegetation patterns found through our analysis. Second, we provide the results of the comparisons we conducted between reference and restoration site data. Our conclusions and recommendations are provided in Section 4. We summarize our conclusions regarding ecological zonation in the estuary and also evaluate the usefulness of the metrics used for comparison between reference and restoration sites. Finally, we provide recommendations for future efforts. Sources cited in the text are listed in Section 5. Appendices A through C provide additional detail on site water temperatures and plants observed on the reference and study sites, as well as detailed maps of all the sites examined in this study.

2.0 Methods

Our methods for reference wetland site selection, data collection, and data summarization are detailed in the RS study 2010 final report (Borde et al. 2011) and accordingly will not be described in full here. The methods we present here pertain to the selection of restoration sites for inclusion in this study, data summarization for the restoration sites, and data analysis for both reference and restoration sites.

2.1 Study Sites

We included 51 reference sites and 10 restoration sites in this study (Figure 2.1). Site selection criteria for the reference sites included habitat type, location, hydrogeomorphic setting, access, proximity to known restoration efforts, and access, as described in Borde et al. (2008a). Despite an extensive reconnaissance effort, only a very limited number of sites met these criteria, so a random selection of sites was not possible. However, efforts were made to sample a broad distribution of sites both spatially and in all wetland types (forested, shrub, and emergent).

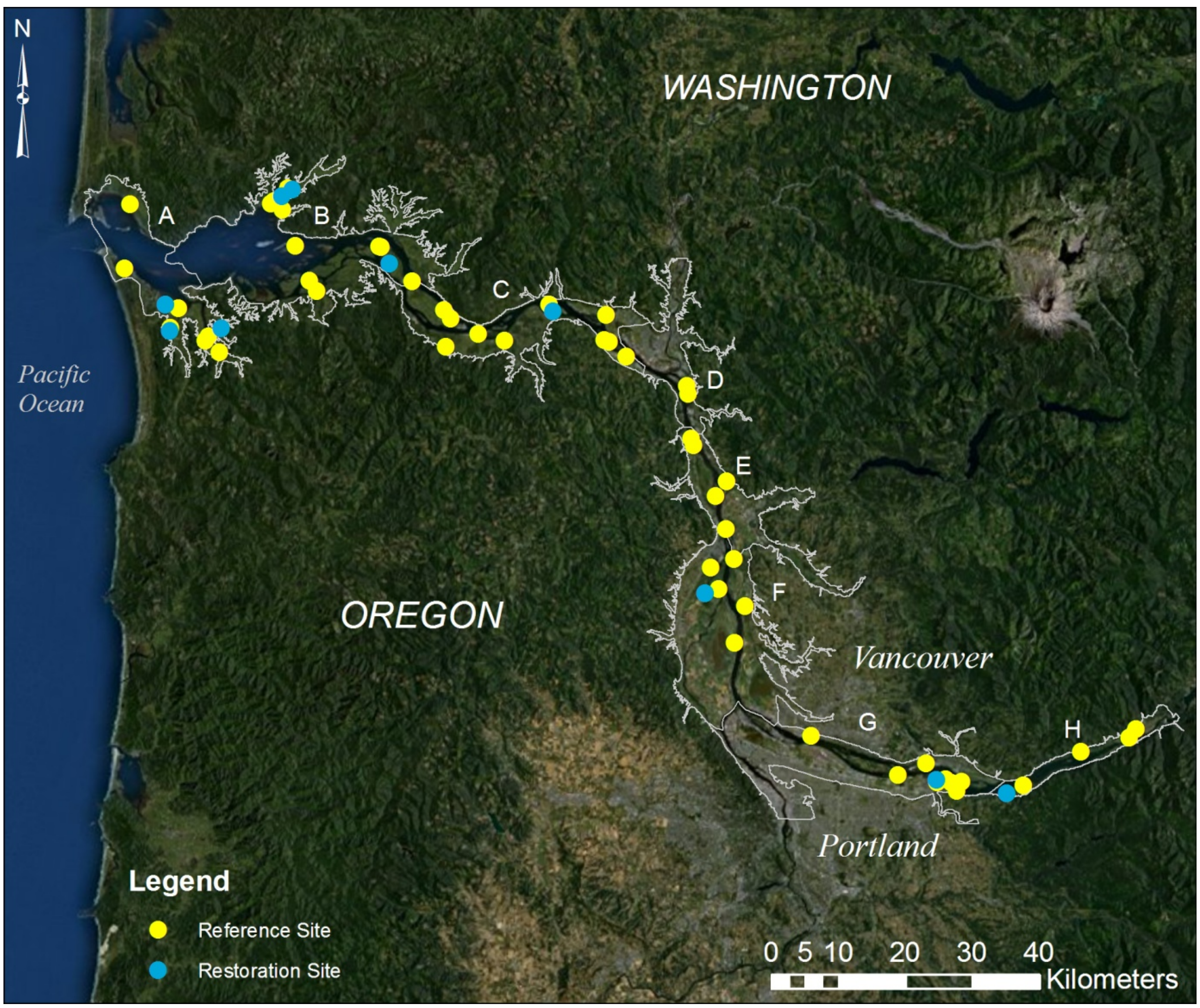


Figure 2.1. Reference and restoration sites in the lower Columbia River and estuary.

Information gathered in this study helps to illuminate our understanding of the trajectory of restoration sites progressing from a state of early development through successional stages to a stable and resilient state more like undisturbed reference sites. Likewise, three categories of sites are included in this study, as follows:

- least-disturbed habitat – These sites include several specific habitat types, such as brackish marshes, tidal freshwater marshes, tidal freshwater shrub/scrub, tidal freshwater forested swamps (dominated by Sitka spruce), and riparian woodlands (dominated by Black cottonwood, Oregon ash and Pacific willow). Some of these sites were present on the 1880 historical maps, while others have developed since that time. However, none of the sites are a result of direct physical disturbances at the sites. These sites provide the most stable endpoint on the trajectory for comparison to restoration sites.
- previously breached habitat – These sites are previously diked areas that were breached either by natural forces or by intentional restoration actions 10 to 50 years ago. The sites have begun their progression back to a pre-diked state and therefore provide data points along the restoration trajectory.
- created habitat – These island sites were created from dredged material placement. The age of these sites can be estimated and the structure and function evaluated to predict the potential restoration trajectories for these types of habitats.

More discussion regarding the distinction between these types of sites is provided in Borde et al. (2011). For the analyses in this report, all types of sites were included and the history of the sites was used to provide context for the results.

The reference sites used in this study are listed in Table 2.1, and maps of each site are included in Appendix C. Each site was given a code, which will be used throughout the rest of the report. In general, the first two letters of the code represent the site initials and the last letter designates the type of site. For example, CCR represents the Coal Creek Riparian site. The type designations are as follows:

S swamp (a forested evergreen tree dominated wetland)
shrub (shrub dominated wetland)
R riparian (a forested deciduous tree dominated wetland)
M marsh (an herbaceous, emergent wetland; some were present on historical maps from the 1880s[1])
B previously diked marsh (breached accidentally or for restoration more than 10 years ago)
C created marsh (not present on historical maps and likely due to placement of dredged material).

The restoration sites were selected based primarily on three criteria: 1) the project had been completed for at least one year, 2) post-restoration monitoring data had been collected, and 3) data were available. The ten sites that best met these criteria were included in this study, as summarized in Table 2.2. For many of these restoration sites, data for all of the metrics that were sampled at the reference sites were unavailable, so comparative analyses were conducted on metrics with available data only.

[1] Historical maps for the Columbia River are available online at http://historicalcharts.noaa.gov/ and were recently georeferenced and digitized (Burke 2010).

Table 2.1. Reference sites included in this study.

Site Name	Site Code	Distance from Col. River mouth (rkm)	Reach	Habitat Type	Historical Class
Trestle Bay	TBB	12	A	marsh	breach
Chinook River Mouth	CHM	12	A	marsh	least-disturbed
Fort Clatsop	FCB	19	A	marsh	breach
Mouth Lewis & Clark River	LCM	20	A	marsh	least-disturbed
Haven Island	HIB	23	A	marsh	breach
Cooperage Slough	CSM	23	A	marsh	least-disturbed
Grant Island	GIM	23	A	marsh	least-disturbed
Crooked Creek	CCS	37	B	forested	least-disturbed
Secret River Swamp	SRS	37	B	forested	least-disturbed
Seal Slough	SSS	37	B	forested	least-disturbed
Secret River Marsh	SRM	37	B	marsh	least-disturbed
Miller Sands	MSC	39	B	marsh	created
Karlson Island 2	KIS	40	B	forested	least-disturbed
Karlson Island	KIB	41	B	marsh	breach
Welch Island	WIM	53	B	marsh	least-disturbed
Welch Island	WIS	53	B	shrub	least-disturbed
Ryan Island	RIM	61	C	marsh	least-disturbed
Jackson Island	JIC	71	C	marsh	created
Whites Island	WHC	72	C	marsh	created
Westport Slough	WSS	73	C	shrub	least-disturbed
Wallace Island - west	WAC	77	C	marsh	created
Clatskanie River - Anunde Is.	CRM	80	C	marsh	least-disturbed
Gull Island	GUC	89	C	marsh	created
Coal Creek Slough	CCR	98	C	forested	least-disturbed
Lord Island 1	LI1	99	C	marsh	created
Lord Island 2	LI2	100	C	marsh	created
Dibblee Slough	DSC	104	C	marsh	created
Cottonwood Island 1	CI1	113	D	marsh	created
Cottonwood Island 2	CI2	114	D	marsh	created
Sandy Island 1	SI1	121	E	marsh	created
Sandy Island 2	SI2	123	E	marsh	created
Martin Island	MIM	129	E	marsh	least-disturbed
Goat Island	GIC	131	E	marsh	created
No-name Island	NNI	136	E	marsh	created
Gee Creek	GCR	141	F	forested	least-disturbed
Scappoose Bay	SBM	143	F	marsh	least-disturbed
Cunningham Lake	CLM	145	F	marsh	least-disturbed
Campbell Slough	CS1	149	F	marsh	least-disturbed
Sauvie Island East Slough	SSC	154	F	marsh	created
Water Resources Center	WRC	175	G	marsh	least-disturbed
McGuire Island	MIC	190	G	marsh	created

Table 2.1. (contd)

Site Name	Site Code	Distance from Col. River mouth (rkm)	Reach	Habitat Type	Historical Class
Washougal River mouth	WRM	195	G	marsh	least-disturbed
Sandy River Channel (old)	OSR	196	G	marsh	least-disturbed
Sandy River Delta (old)	OSM	198	G	marsh	least-disturbed
Gary Island	GAM	200	G	marsh	least-disturbed
Chattham Island	CIC	201	G	marsh	created
Reed Island	RIC	201	G	marsh	created
Sand Island (Rooster Rock)	SIM	211	H	marsh	least-disturbed
Franz Lake	FLM	221	H	marsh	least-disturbed
Pierce Island	PIM	228	H	marsh	least-disturbed
Hardy Creek	HCM	230	H	marsh	least-disturbed

Table 2.2. Restoration sites included in this study.

Site Name	Site Code	Distance from CR Mouth (rkm)	Landscape Setting	Location	Restoration Year	Restoration Action	Target Habitat
Fort Clatsop	FC	19[(a)]	Tributary	Lewis & Clark River	2007	Hydrologic Reconnection – tide gate to bridge	Forested Wetland
Vera Slough	VS	19	Bay	Youngs Bay	2005	Hydrologic Reconnection – tide gate replacement	Emergent/ Shrub Wetland
Walluski	WA	19[(a)]	Tributary	Walluski River	2006	Hydrologic Reconnection – dike breach	Forested Wetland
Devil’s Elbow	DE	37[(a)]	Tributary	Grays River	2004	Hydrologic Reconnection – dike breach	Forested Wetland
Kandoll Farm	KF	37[(a)]	Tributary	Grays River	2005	Hydrologic Reconnection – tide gate to 13’ culverts	Forested Wetland
Tenasillahee Island	TI	57	Island	Mainstem	2007	Hydrologic Reconnection – tide gate replacement	Emergent/ Shrub Wetland
Crims Island	CI	90	Island	Mainstem	2005	Hydrologic Reconnection – excavation	Emergent Wetland
Hogan Ranch	HR	146	Mainland	Scappoose Bay	2004	Enhancement – cattle exclusion and plantings	Emergent Wetland
Sandy River Delta	SRD	196	Delta	Mainstem	2005; 2006	Enhancement – plantings	Riparian Forest
Mirror Lake	ML	208	Mainland	Mainstem	2005; 2008	Enhancement – fish passage improvement and plantings	Emergent Wetland/ Riparian

(a) These sites are located up tributaries. In these cases, the distance from the Columbia River mouth represents the distance to the mouth of the tributary, not the distance up the tributary.

2.2 Data Management

Data from the RS study were organized and normalized (i.e., ensuring consistency and reducing redundancy) as part of previous and concurrent efforts (Borde et al. 2011, 2012). Data were gathered from restoration projects that were known to have data for at least two metrics (Table 2.3). However, before analyses could be performed, data from the restoration sites needed to be organized, normalized, processed, and combined with the RS datasets. For example, vegetation data were updated to use the most recent nomenclature, and all data were transferred to continuous datasets with consistent units. In addition, water pressure data were corrected for barometric pressure and converted to water surface elevation. All metrics required some level of manipulation prior to analysis.

Table 2.3. Metrics for which data were available from the restoration sites included in this study.

Site Name	Code	Distance from CR Mouth (rkm)	Vegetation	Elevation	Sediment Accretion	Channel Cross Section	Hydrology	Temperature
Fort Clatsop	FC	19[a]	x		x	x	x	x
Vera Slough	VS	19	x	x	x	x	x	x
Walluski	WA	19[a]			x	x		
Devils Elbow	DE	37[a]			x			
Kandoll Farm	KF	37[a]	x	x	x	x	x	x
Tenasillahee Island	TI	57						x
Crims Island	CI	90	x	x	x	x	x	x
Hogan Ranch	HR	146	x					x
Sandy River Delta	SRD	196	x					
Mirror Lake	ML	208	x			x		x

(a) These sites are located up tributaries. Therefore, the distance from the Columbia River mouth represents the distance to the mouth of the tributary, not the distance up the tributary.

2.3 Data Analysis

2.3.1 Vegetation Distribution Patterns

The distribution of wetland vegetation and its association with inundation patterns in the tidally influenced Columbia River was explored using data from the reference sites. Five habitat classifications based on the community and historical activities were used to separate wetlands (forested; shrub; marsh-breach; marsh-created; and marsh-least-disturbed). At each of the marsh sites, variable numbers of quadrats positioned at roughly 10-m intervals along transects at each site were assessed for the cover of wetland vegetation and elevation (relative to Columbia River Datum, CRD). For each quadrat sampled, the absolute percentage of cover was recorded for each vegetative layer (e.g., canopy, understory). Total cover was defined as the sum of all observed (both unidentified and identified) grasses, ferns, herbs, rushes, and sedges. Relative cover was then calculated as the ratio of the absolute cover divided by the total cover. Only identified grasses, ferns, herbs, rushes, and sedges were used in the analyses on percentage cover (Table 2.4).

Table 2.4. Classification and number of identified wetland taxa observed within quadrats from marsh sites only.

Plant Type	Number of Species	Number of Observations	Maximum Absolute Cover (%)	Used in Discriminant Analysis	Number of Quadrats
Algae	1	3	5	No	334
Arrow-grass	1	37	30	No	
Shrub	13	302	115	No	
Tree	3	24	100	No	
Grass	16	1898	110	Yes	1614
Fern	6	524	95	Yes	2455
Herb	105	5138	100	Yes	
Rush	10	168	100	Yes	
Sedge	18	2241	100	Yes	
Grand Total	173	10,335	--	--	2811

Cover data are often patchy and highly variable, and a few large observations can influence the mean and potentially distort a comparative analysis. For highly skewed data with many zeros, the mean can be a poor representation of the typical value in a distribution because it is greatly inflated by a few extreme values (Figure 2.2). The median and 75th percentile, however, are based on ranks and are unaffected by extreme values. Therefore, because of the number of zero observations, the median cover would equal zero, thus the 75th percentile of cover was used to represent the species cover for a given marsh. The average over years for sites visited more than once was also calculated.

Analysis was conducted on the 75th percentile of cover for each plant observed at a site. Plants used in the model were observed at a minimum of three sites and yielded a maximum percentage cover of 5% at one or more sites. Breakpoints for discrimination of vegetation communities were developed based on several lines of evidence, including salinity, hydrology (sum exceedance value [SEV] see Borde et al. 2011), species distribution, and species richness, and are discussed in Section 3.1.1. As part of this analysis, the probability of occurrence for species in marsh reference sites was calculated by dividing the number of occurrences where the species had the maximum cover (>20%) in a quadrat by the total number of quadrats in the estuary. Cluster analysis of least-disturbed marshes was conducted on standardized variables using complete linkage and Euclidean distance (squared distance between observations) and Manhattan distance (absolute difference between observations). Discriminant analysis was conducted based on the location within the river. Breakpoint values in the emergent marsh (EM) model (EM1 = 40, EM2 = 104, EM3 = 136, and EM4 = 181) determined the boundaries for the resulting hydro-vegetation zones.

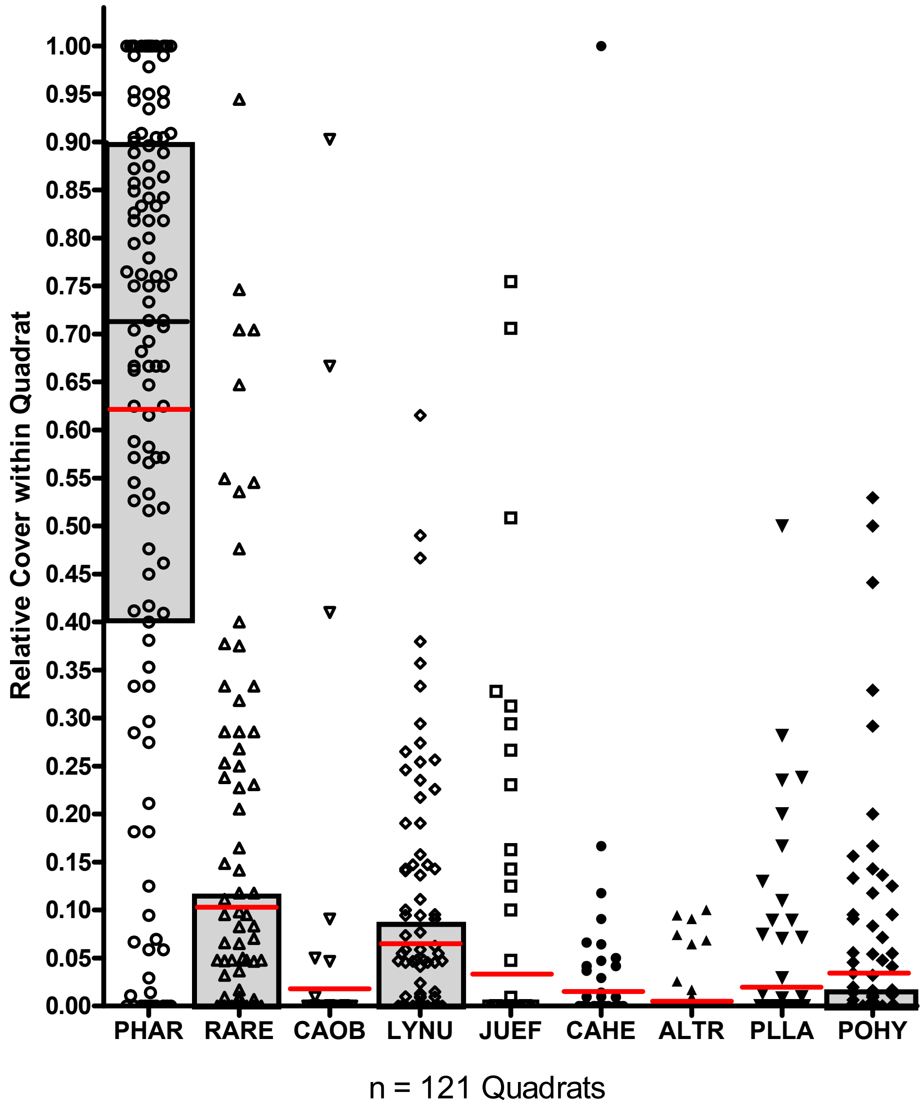


Figure 2.2. Comparison of the mean (red line), median (black line within gray rectangle), and the 25th and 75th percentile (bottom and top of gray rectangle) of vegetation cover data from Kandoll Farm. Species codes (on the *x*-axis) are provided in Appendix A.

2.3.1.1 Elevation Distribution of the Major Herbaceous Species

The elevation distribution for major plant species within a given section of the river based on the EM model was estimated. The data used in the analysis were the relative cover of each species within quadrats for which elevation had been measured. For each elevation (relative to the Columbia River Datum [CRD] and rounded to one decimal place) and species, the 75th percentile of the relative cover from all sites having measurements at that elevation was calculated. For each species, the elevation distribution was characterized by the minimum and maximum elevations for which the 75th percentile was greater than 20% cover. The species considered in the analysis were those observed at least 20 times. For hydro-vegetation zone 1, the analysis was conducted for those sites on the main stem of the river and within tributaries separately. The species used in these river sections were those observed at least 10 times.

2.3.1.2 Hydrology

Hydrology and the resulting inundation patterns are an important factor in the distribution of wetland inundation. As part of the analysis of vegetation distribution patterns in the LCRE, we also evaluated inundation. Pressure transducers (HOBO Water Level Data Loggers, Onset Computer Corporation) were deployed when possible at each of the reference sites as a means of logging in situ water level data for one year. Pressure data were corrected for atmospheric pressure and converted to water surface elevation using the surveyed elevation of the sensor. These data were used to calculate the frequency of inundation and the SEV for site-specific marsh elevations.

The frequency of marsh inundation was calculated for the entire period of record (approximately one year) and for the growing season, 22 April–12 October. The growing season is based on the number of frost-free days for the region, as determined by the Natural Resource Conservation Service (NRCS) in the wetland determination table for Clark County, WA (NRCS 2002). The Clark County growing season is used for all the sites in the estuary so that the inundation calculations are standardized to one period. The inundation frequency during the growing season was calculated during daylight hours only (between 0900 hours and 1700 hours). This limitation was employed because of the tidal areas where the timing of the daily high tide can be a factor in the amount of time available for plants to photosynthesize.

The SEV is a single measurement that incorporates magnitude, timing, and duration of surface water flooding and has been used for evaluating the effect of variable water levels on vegetation (Simon et al. 1997; Gowing et al. 2002; Araya et al. 2011). We calculated the SEV using the following equation:

$$\mathrm{SEV} = \sum_{i=1}^{n} (d_{\mathrm{elev}})$$

where n is the number of hours present in the time period evaluated, and d_{elev} is the hourly water surface elevation above the average marsh elevation. This differs from previous LCRE studies (Borde et al. 2011, 2012) in which the daily mean water surface elevation was used in the calculation rather than the hourly water level elevation used here. The latter was chosen to ensure we captured daily inundation fluctuations that occur in the more tidally dominated sites. The time periods evaluated were the annual deployment period and the growing season. Both periods were standardized to include the same days in each year, as follows:

- growing season – 22 April to 22 June and 20 August to 13 October (115 days)
- annual deployment period – 20 August to 22 June (of the next year; 306 days).

Adoption of this standardization was necessary because the deployment and retrieval dates for sensors varied in the past, between 21 June and 20 August; to compare calculations from past and current data required that the same time periods be used.

2.3.2 Reference and Restoration Site Comparison

Data analysis was conducted for the metrics available from each wetland reference and restoration site. In most cases, summary calculations were made, after which comparisons or statistical tests were applied to the summarized data.

2.3.2.1 Sediment Accretion Rate

Annual sediment accretion rates were calculated as the difference between annual measurements at sediment stakes deployed at each site (see Borde et al. 2011 and Roegner et al. 2009 for field methods). Rates for reference to restoration sites were plotted for the appropriate hydro-vegetation zone.

2.3.2.2 Elevation

Elevation data were collected at each of the vegetation sample quadrats at three restoration sites (VS, KF, and CI) and at all the reference sites. The data were collected in North American Vertical Datum 1988 (NAVD88) and were converted to mean lower low water (MLLW) below rkm 35 and to the Columbia River Datum (CRD) between rkm 35 and 235 (see Borde et al. 2011 for methods regarding the conversion). The conversion from the terrestrial datum NAVD88 to the water level-related datums allowed comparison of elevations between sites along the estuarine gradient. The data at each site were summarized to determine average, minimum, and maximum elevations for each sample area. These results were than compared between the restoration sites and to the selected reference sites in each hydro-vegetation zone.

2.3.2.3 Hydrology

The SEV was calculated for the elevation range of the restoration and the appropriate reference sites sites. The range of values were then plotted together to compare the values at the reference sites to each restoration site.

2.3.2.4 Temperature

Hourly water temperature data were collected in the field using in situ autonomous data loggers for varying time periods between 2005 and 2010. The seven-day running average of the daily maximum (7DADmax) was calculated for seven restoration sites (FC, VS, KF, TI, CI, HR, and ML) and 25 reference sites using MATLAB (The MathWorks, Inc., Natick, Massachusetts). Only the period between March and July was calculated because this coincides with the period of peak juvenile Chinook salmon migration (Sather et al. 2011), and data gaps tended to occur with summer sensor download and launch dates. The data for the restoration sites were plotted relative to the Washington State Department of Ecology (WADOE) surface water criterion of 17.5°C (see http://www.ecy.wa.gov/programs/wq/swqs) and compared to the selected reference sites in each hydro-vegetation zone.

2.3.2.5 Vegetation

Bivariate Analysis

One means of evaluating the vegetation community structure is through bivariate analysis. Simply put, this means comparing two related variables. We chose two commonly occurring vegetation species in the reference sites of each hydro-vegetation zone and plotted them against each other using percentage cover values. Each restoration site and the selected reference sites were plotted on the same graph for comparison.

Probability of Occurrence

The probability of occurrence was calculated as a means of comparing the least-disturbed marsh reference sites to restoration sites within each hydro-vegetation zone. The probability of occurrence was calculated by dividing the number of occurrences where the species had the maximum cover (>20%) in a quadrat by the total number of quadrats sampled in the estuary. For restoration sites, the probability of occurrence was defined based on cover greater than 14%. The species plotted for comparison were those observed to have maximum cover greater than or equal to 5% for least-disturbed-marsh plants, and those plants that occur greater than 10% at the restoration sites.

Similarity Index

Similarity indices for herbaceous, shrub, and tree vegetation cover were calculated individually using PCORD Version 5.32 software (McCune and Grace 2002). The data used to calculate similarity between sites were herbaceous species cover, shrub species stem density, and tree species stem density. Data were summarized in a matrix of the mean percentage cover or stem density of each species at each site. All sampled plots were incorporated into the mean for each site, with the exception of tree plantings at Sandy River, which occurred in four subareas numbered 1–4 and were monitored and calculated accordingly. To express dissimilarity, we calculated the Relative Sorensen proportion coefficient, also known as the relativized Manhattan coefficient (Faith et al. 1987), and converted the results to similarity by subtracting from 1.0. Proportion coefficients are "city-block distance measures expressed as proportions of the maximum distance possible" (McCune and Grace 2002, p.47). The Relative Sorensen method uses the Bray–Curtis dissimilarity measure,

$$D_{ih} = 1 - \frac{2\sum_{j=1}^{p} Min(a_{ij}, a_{hj})}{\sum_{j=1}^{p} a_{ij} + \sum_{j=1}^{p} a_{hj}}$$

on data (for the ith site and the j species, a_{ij}) that has been made relative by dividing each species cover (j = 1 to the number of species, p) by the sample unit totals. In this case, a sample unit total is the total percentage cover of all herbaceous species at a site, total stem density of all tree species at a site, or total stem density of all shrub species at a site.

2.3.2.6 Tidal Channels

Tidal channel morphometrics were calculated for all sites with tidal channels. The length of the primary channel was measured using geographic information system (GIS) data. The channel area, depth, and width at the outlet were calculated based on cross-sectional measurements in the field. The relationship between area at the outlet versus length and channel width versus depth at the outlet were plotted for reference and restoration sites.

3.0 Results and Discussion

We first present the results of our analysis of vegetation patterns found in wetland reference sites, which can be useful for restoration planning and design, followed by a comparison of data from the reference sites and restoration sites. We begin by developing the basis for the distribution of vegetation characteristic of reference sites in the region using available ecological and hydrological data. We then use discriminant function analysis using the vegetation data from the least disturbed sites to provide verification for the observed hydro-vegetation zonation. We conclude the analysis of vegetation patterns by providing the elevational ranges of selected plant species and communities for different zones of the LCRE. Finally, we compare reference sites to restoration sites within each of these zones; evaluating several metrics including accretion rates, elevation, temperature, vegetation, and channel morphology.

3.1 Vegetation Zonation Data

3.1.1 Vegetation Distribution Patterns along the Estuarine Gradient

We used several different lines of evidence based on vegetation species richness, species composition, salinity, and inundation to determine vegetation distribution patterns along the estuarine gradient. First, species richness differs spatially in the estuary; fewer species are present at the lower and upper ends of the estuary, and species richness is higher in the middle reaches (Figure 3.1). We suspect that the longitudinal gradient (i.e., river mouth to Bonneville Dam) in plant species richness and plant cover is caused by a combination of several factors. Grime (1979) proposed that the major factors structuring species composition and abundance were 1) dominance (competitive exclusion), 2) environmental stress, 3) disturbance, 4) niche differentiation, and 5) colonization. Grace (1999) summarized these factors into a conceptual model.

We believe that all of these factors contribute to the floodplain wetland plant community and that water level dynamics exhibit a strong influence. We believe that the relationship of low richness at the ends of the estuarine gradient and higher richness in the middle region of the gradient is largely due to the 'disturbance' associated with water-level dynamics (i.e., tidal, fluvial), and water properties (i.e., salinity) (Table 3.1). Physical disturbance has been shown to control species richness in many ecosystems (e.g., Levin and Paine 1974, Connell 1978, Bertness and Ellison 1987). Another contributing factor could be the species pool available for colonization of sites (Aarssen and Schamp 2002), which may be greatest at the middle reaches of the lower river.

Species composition also differs along the estuarine gradient; some species have a higher affinity for the tidally dominated areas closer to the mouth and others have a higher affinity for the more fluvial-dominated areas, as indicated by the proportional probability of occurrence (Table 3.2). In Table 3.2, the species in the first three columns are likely to occur throughout the estuary, while the remaining species are found primarily in either the lower or the upper portions of the estuary. Sites within hydro-vegetation zones 2 and 3 typically have the highest species diversity because there is overlap between the species that can occur in the lower portion and those that have a higher affinity for the upper portion of the estuary.

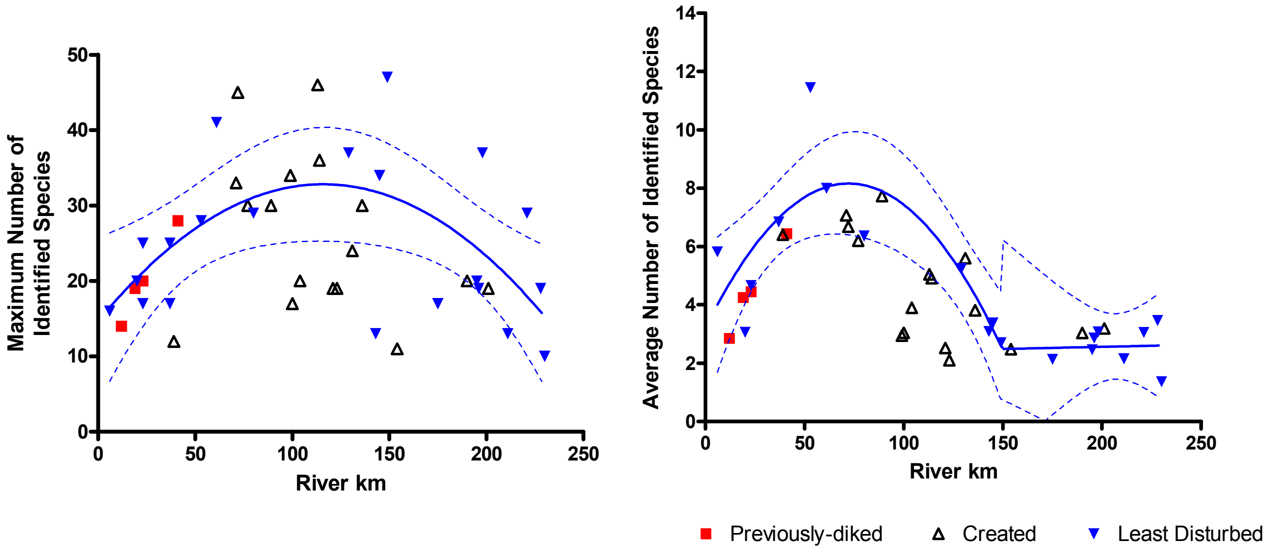


Figure 3.1. Maximum number (upper panel) and average number (lower panel) of species observed at the reference sites versus the distance of the sites from the river mouth. The mid-river section, associated with the peak of the quadratic curves, had significantly more identified species than the lower and upper portions of the river (Kruskal–Wallis; $p = 0.008$). The fitted curves and the confidence intervals were based on the least-disturbed marsh sites only.

Table 3.1. Relationships between water level dynamics, water properties, and vegetation species richness and cover in the lower Columbia River based on our findings.

High cover	• Low plant diversity • Stress tolerant and ruderal • Euryhaline		
Moderate cover		• High plant diversity, • Competitive, stress tolerant, and ruderal • Freshwater	
Low cover			• Low plant diversity • Stress tolerant and ruderal dominated, • Freshwater
	SEV low (Tidal, regular daily inundation)	**SEV moderate** (Mixed tidal/fluvial, irregular seasonal inundation)	**SEV high** (Fluvial, persistent high water at freshet)

Table 3.2. Probability of the most common vegetation species occurring at each marsh reference site (species codes are provided in Appendix A). Sites are ordered by location beginning at the river mouth. Cells highlighted dark green indicate a greater than 50% probability of occurrence at that site, light green 50–20%, and yellow less than 20%.

Site Code	rkm	PHAR	ELPA	CAOB	OESA	LIOC	SCAM	SPAN	ELAC	CAHE	CALY	MYSP	SCTA	LEOR	SALA	ELCA	LUPA
Zone 1 rkm 0 - 39																	
Mainstem																	
CHM	12					0.2	0.3		0.4		0.9						
TBB	12										0.4	0.1					
LCM	20	0.3			0.1						0.8		0.1				
SRM-H	37	0.4			0.6			0.2			0.8		0.2				
SRM-L	37	0.4	0.2			0.2		0.2		0.2			0.4				
MSC	39					0.4			0.4	0.6		0.3					
Tributary																	
FCB	19	0.3	0.2	0.5	0.3						0.2	0.3					
CSM	23			0.6									0.5				
GIM	23				0.3					0.2	0.7		0.1				
HIB	23	0.4	0.1			0.1				0.4	0.3		0.3				
Zone 2 rkm 40 - 103																	
KIB	41	0.2	0.2	0.4	0.1			0.1		0.2		0.3					
WIM	53			0.5													
RIM	61	0.3	0.1						0.1		0.6					0.1	
JIM	71	0.4	0.2		0.1		0.1		0.1	0.3	0.5		0.1		0.6	0.3	
WHM	72	0.7	0.1		0.1					0.1	0.3	0.1			0.3	0.3	
WAC	77	0.6								0.1	0.2			0.1	0.1	0.3	
CRM	80	0.8	0.1				0.1					0.3			0.5	0.2	
GUC	89		0.6	0.3			0.1					0.4		0.1	0.2		
LI1	99	0.5	0.1			0.0						0.0			0.1	0.4	
Zone 3 rkm 104 - 135																	
LI2	100	0.3	0.1						0.1			0.1		0.1	0.6		
DIB	104	0.6	0.6			0.1			0.2						0.2	0.1	
CI1	113	0.5	0.4	0.1								0.1		0.1	0.2	0.2	
CI2	114	0.5	0.7									0.1	0.3		0.3	0.1	
SI1	121	0.5	0.6				0.1			0.1			0.1		0.4	0.1	
SI2	123	0.6	0.4				0.2							0.1	0.4	0.1	
MIM	129	0.5	0.5	0.3										0.1	0.2	0.3	0.2
GIC	131	0.4	0.6			0.1			0.1					0.1		0.1	0.1
DSI	136	0.5	0.8			0.2								0.3		0.1	0.1
Zone 4 rkm 136 - 180																	
SBM	143	0.6	0.4												1.0		
CLM	145	0.6	0.6												0.6		
CS	149	0.6	0.4												0.4		
SCM	154	0.4	0.3												0.6		0.1
WRC	175	0.7	0.1	0.1											0.4		0.2
Zone 5 rkm 181 -235																	
MIC	190	0.4	0.5	0.2											0.1	0.1	
WRM	195	0.9						0.1	0.1							0.1	0.1
SRD	196	0.9	0.4					0.1				0.1			0.2	0.3	
OSM	198	0.0	0.3									0.1			0.1	0.2	0.1
CIC	201	0.5	1.0														
SIM	211	0.4	0.8										0.2		0.1		0.1
FLM	221	0.8	0.1	0.1											0.4		0.0
PIM	228	0.5	0.5														
HC	230	0.8															

3.1.1.1 Downstream of River Kilometer 40

Downstream of rkm 40, salinity is a factor affecting the lower estuary vegetation distribution patterns. Euryhaline species such as *Carex lyngbyei* (CALY), *Oenanthe sarmentosa* (OESA), and *Lilaeopsis occidentalis* (LIOC) are found more frequently below rkm 40 (Table 3.2). Furthermore, from the literature we determined that rkm 40 is a reasonable estimate for the upper limit of salinity intrusion in marshes. Chawla et al. (2008) states rkm 42 is the salinity intrusion limit during low freshet flow (Bonneville Dam outflow = 3160 m^3/s). Annual low flows can be as low as 2000 m^3/s in the dry season, likely resulting in more extended saltwater intrusion. For example, unpublished results show that salinity intrusion extended along the river bottom to Three-Tree Point (rkm 50) during low-flow neap tides in 1990 (David Jay, Portland State University, personal communication, February 22, 2010). Because these estimates are based on salinity values along the river bottom where the higher salinity concentrations are located, we feel 40 rkm is a more conservative estimate of the extent of salinity in the upper portions of the water column that would likely reach the vegetated marsh surface.

3.1.1.2 Between River Kilometers 40 and 104

Salinity is not a factor between rkm 40 and 104, but inundation is predominantly tidally driven. The amount of inundation occurring at all elevations during the entire year is equal to or greater than that during the growing season (see Section 2.3.1.2 in the methods for descriptions of the time periods used in SEV calculation). In Figure 3.2, the red lines represent sites downstream of rkm 104, where a greater amount of inundation occurs in the winter (non-growing season) months at higher elevations of the sites. This is likely driven by winter flooding and winter high tides that occur in this zone. In contrast, the black lines represent sites where most of the inundation occurs during the growing season.

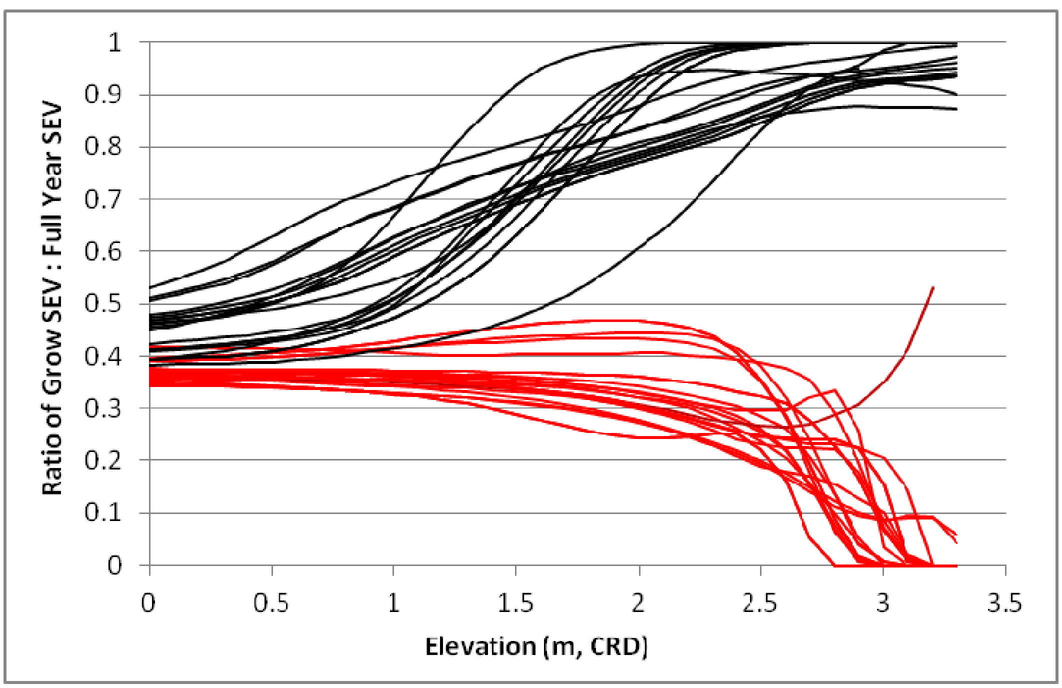


Figure 3.2. Ratio of growing season SEV to the 10-month SEV. Red lines = sites below rkm 104; black lines = sites at or above rkm 104.

For least-disturbed marshes only, 13 plant species were observed at three or more locations between rkm 6 and rkm 230; one or more sites had greater than 5% cover. Cluster analysis on the standardized plant cover denoted eight clusters for two distance measures (Figure 3.3). The two clustering distance measures indicated that marshes from rkm 6 to rkm 37 were at least 50% similar in terms of species composition and cover. Both methods also indicated that marshes from rkm 53 to rkm 80 were at least 50% similar. These clusters are consistent with the discriminant cutoff values of EM1 = 40 and EM2 = 104. Except for site PIM, both methods indicated the same single-site clusters (CSM, SRM-L, WRC, and GAM).

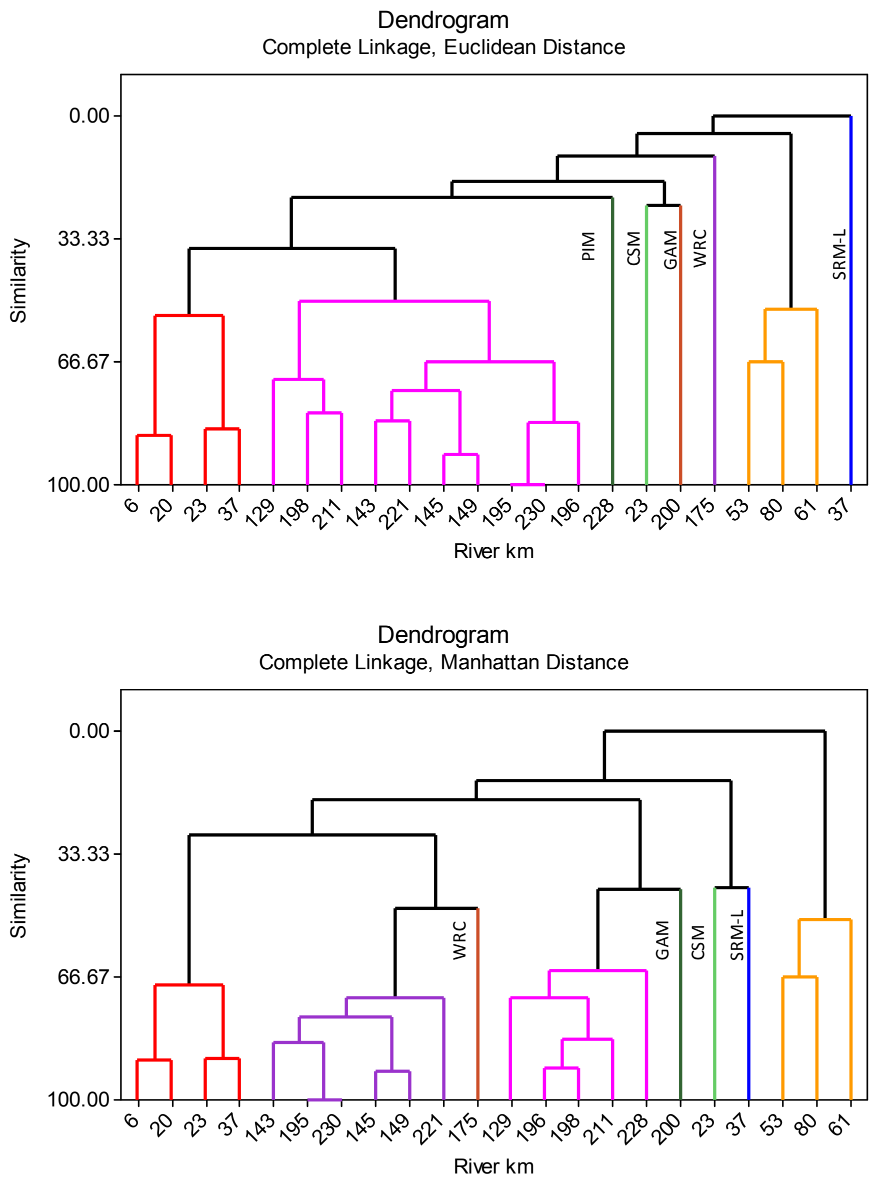


Figure 3.3. Cluster analysis of least-disturbed marshes denoted by river kilometer and color. Colors indicate sites at least 50% similar in terms of species composition and cover. Site codes are provided for the sites that were least similar to the other least-disturbed sites.

3.1.1.3 Between River Kilometers 104 and 136

Upstream of rkm 104, there is a shift in the timing of inundation; a greater proportion of the inundation occurs during the growing season and not spread throughout the year (Figure 3.2). However, the magnitude and duration of inundation is still low relative to the zones farther upriver (Figure 3.4).

3.1.1.4 Between River Kilometers 136 and 181

The magnitude and duration of inundation during the growing season begins to increase between rkm 136 and 181. Kukulka and Jay (2003a, p. 9-10) state "tidal energy input dominates the frequency spectrum from the estuary entrance to at least rkm 135. Further the influence of discharge waves was weak seaward of Columbia City at rkm 135." In accordance with these findings, our analysis of SEV at an elevation of 2 m (CRD) showed that the slope of the $\log_{10}$ growing year SEV as a function of river kilometers is not significantly different from zero downstream of rkm 136 ($p = 0.96$; Figure 3.4), whereas SEV during the growing season was considerably higher above this point. This indicates that the stronger fluvial influence was a driver of the inundation patterns. In addition, Table 3.2 shows that plants that have a high affinity for the conditions found in the lower part of the estuary are not found upstream of rkm 136.

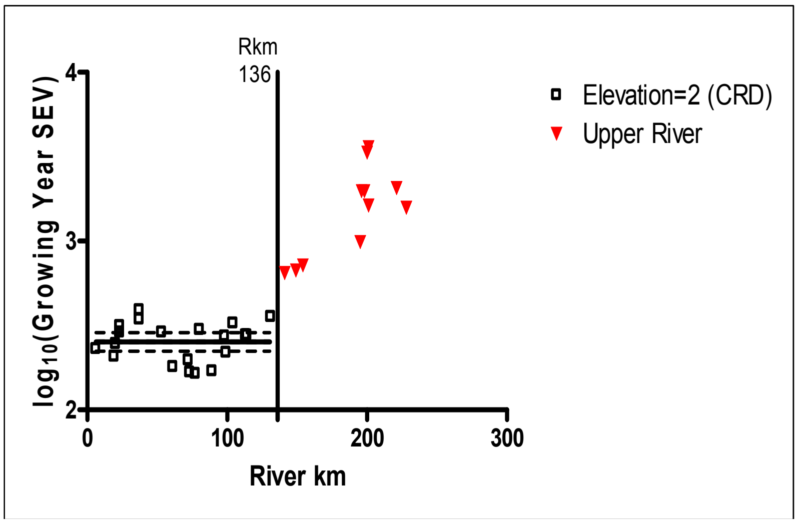


Figure 3.4. The $\log_{10}$ growing season SEV versus river kilometer. In contrast to the slope for the data from upstream of rkm 136, the slope from data downstream of rkm 136 is not significantly different from zero, indicating less variability in the growing season SEV downstream of rkm 136.

3.1.1.5 Above River Kilometer 181

This zone, the closest to the dam, is the most fluvial-dominated zone. Inundation is very high during the growing season (Figure 3.5) when the spring freshet occurs, and is very low during the rest of the year when flows are very low to moderate.

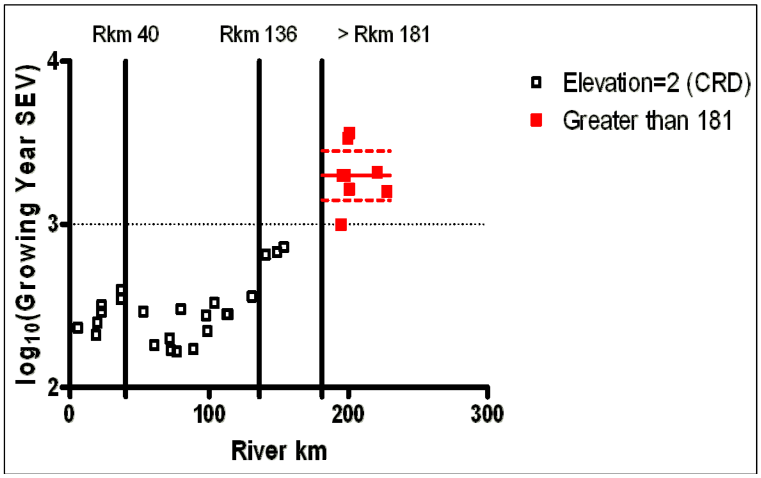


Figure 3.5. The $\log_{10}$ growing year SEV versus river kilometer, with proposed zones delineated. The slope of $\log_{10}$ growing year SEV above rkm 181 was not significantly different from zero.

3.1.1.6 Discriminant Function Analysis

Twenty-two least-disturbed marshes were used in the analysis of cover data for the 13 plant species that occurred at three or more locations between rkm 12 and rkm 230, with greater than 5% cover at one or more sites. Discrimination using the standardized 75th percentile of cover for all 13 plants successfully classified all sites into four emergent marsh groups (EM1, EM2, EM4, and EM5). There was only one least-disturbed site for EM3, Martin Island (MIM), so it was excluded from the analysis. For the discriminant function, two roots explained 98% of the variance. Eigen values for each function were greater than 1, and the Wilks lambda was equal to 0.0001 ($p < 0.0001$). The discriminant scores (Score 1 and Score 2) for all sites (including MIM) were calculated and plotted against each other, providing a visual indication that all five groups would have been discriminated (Figure 3.6).

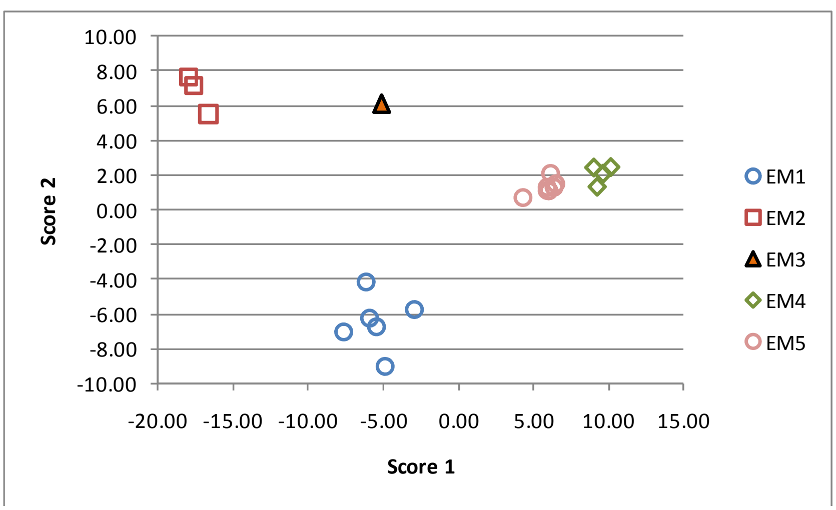


Figure 3.6. Scatter plot of the discriminant scores for five emergent marsh groups. The solid filled triangle was excluded from the discriminant analysis, and scores were calculated without EM3.

In summary, the hydro-vegetation zones were determined by salinity and inundation patterns and have been shown to result in distinct vegetation species composition and cover groups (EM groups). The boundaries of the observed hydro-vegetation zones are shown in Figure 3.7 and should be evaluated with the following considerations:

1. The verification of the boundaries are based on vegetation from least-disturbed marshes only (see methods for definition of term), while the yellow points on the map in Figure 3.7 represent all reference sites (e.g., emergent, shrub, and forested wetlands and breached, created, and least-disturbed).
2. The boundary between zones 4 and 5 is a rough estimate due to the lack of sites in this area.
3. The hydrologic data used in this analysis were collected during a limited period, between 2008 and 2010, and different results may be observed using data from different years.

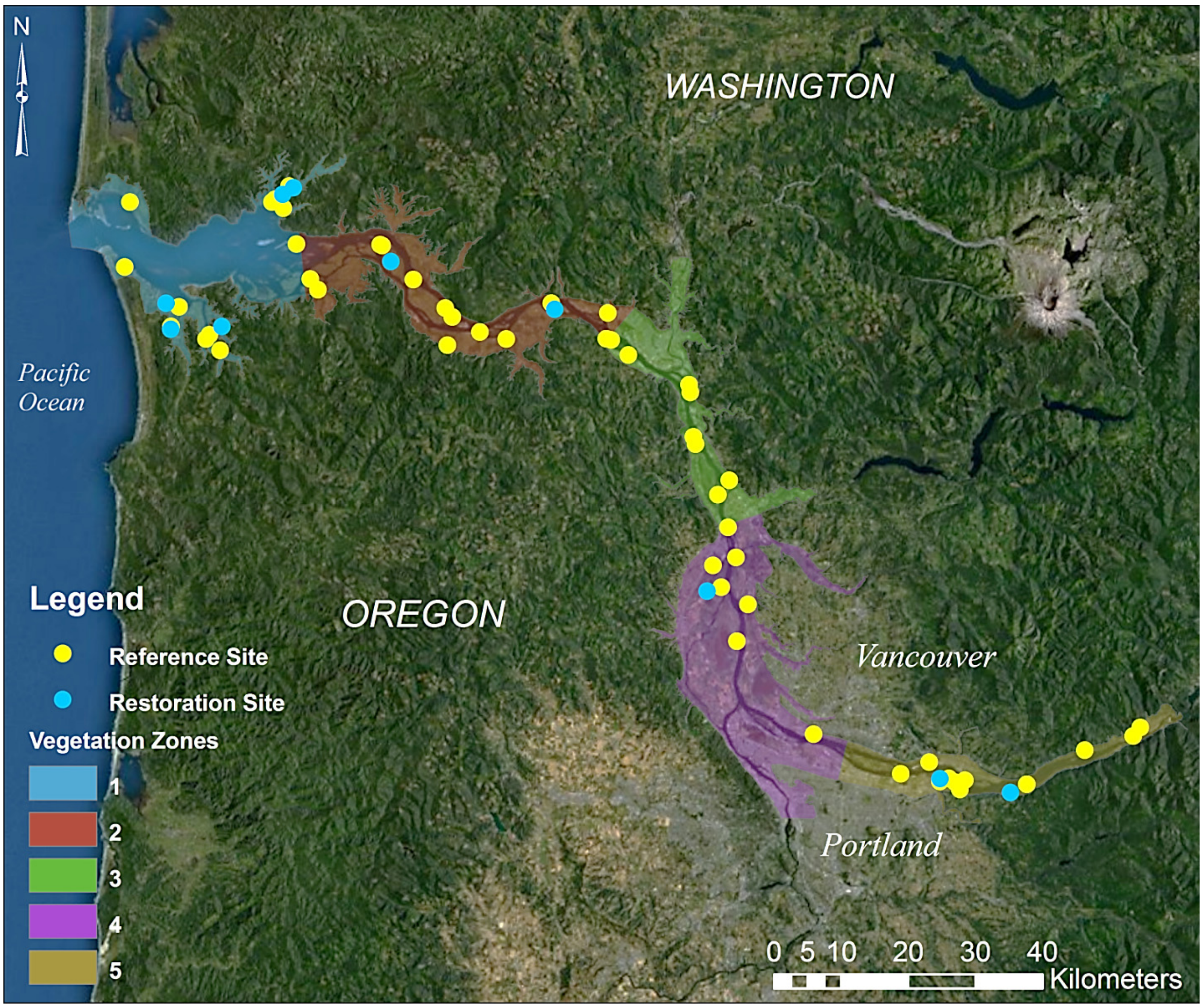


Figure 3.7. Estimated boundaries of the hydro-vegetation zones showing location of reference and restoration sites evaluated in the study.

3.1.2 Vegetation Elevation Ranges

Using the elevation and vegetation data collected at 51 field sites, we are able to develop elevation ranges for the most common species found in each of the hydro-vegetation zones described in the previous section. Table 3.3 shows the elevation range for emergent marshes from two data collection methods: 1) from the vegetation monitoring effort, elevation was determined for the species with the maximum cover in a quadrat having at least 10% relative cover (using a real-time kinematic (RTK) global positioning system GPS), and 2) elevations were collected at the boundaries of vegetation communities during field mapping (using a hand-held GPS and a RTK GPS)[1]. The first method provides elevation ranges for the dominant species, while the second method covers a broader spatial and elevation range. The zones for forested wetlands are based on the landward extent of Sitka spruce (*Picea sitchensis*) along the LCRE (estimated to be approximately rkm 75). The average elevations within shrub and forested wetlands are provided in Table 3.4.

Table 3.3. Marsh elevation ranges and the most common species in each of the hydro-vegetation zones.

Zone	Herbaceous Species	Lower	Upper		Marsh Strata	*n*	Average Lower Elevation	SD Lower	Average Upper Elevation	SD Upper
		Elevation (m, CRD)						Elevation (m, CRD)		
1	SCTA	0.3	0.4		Herbaceous	5	1.1	0.7	2.6	0.6
(mainstem)	LIOC	0.5	0.9		Shrub	3	2.5	0.6	NA	NA
	CALY	1.0	2.4		Tree	2	2.6	0.8	NA	NA
	CACA	1.9	2.5							
	PHAR	2.5	2.7							
1	CAOB/CALY	0.3	2.6		Herbaceous	4	0.9	0.6	2.7	0.2
(tributary)	SCTA	2.2	2.4		Shrub	3	2.5	0.1	NA	NA
	POAN	2.4	2.7		Tree	1	3.0	NA	NA	NA
	ATFI	2.5	2.8							
	PHAR	2.3	2.7							
2	SALA	0.8	1.2		Herbaceous	9	0.9	0.2	2.2	0.3
	ELPA	0.8	1.4		Shrub	2	2.1	0.0	NA	NA
	PHAR	1.4	3.2		Tree	1	1.9	NA	NA	NA
	CALY/CAOB	1.5	1.7							
3	SALA	0.5	1.2		Herbaceous	6	0.7	0.2	2.0	0.4
	ELPA	0.6	1.5		Shrub	3	1.9	0.4	NA	NA
	PHAR	1.4	2.3		Tree	0	NA	NA	NA	NA
4	SALA	0.8	1.4		Herbaceous	4	1.0	0.1	2.0	0.5
	ELPA	0.8	1.7		Shrub	0	NA	NA	NA	NA
	PHAR	1.3	3.8		Tree	0	NA	NA	NA	NA
5	ELPA	0.7	1.7		Herbaceous	7	0.9	0.3	2.3	0.8
	SALA	0.8	0.9		Shrub	6	1.9	0.7	NA	NA
	PHAR	1.5	4.6		Tree	4	3.4	0.9	NA	NA

SD = Standard deviation.
NA = Not available.

[1] See Borde et al. 2011 for detailed field methods.

Table 3.4. Forested and shrub wetland elevation ranges in the two forested wetland vegetation zones.

rkm	Forested/Shrub Wetland Strata	*n*	Average Lower Elevation	SD Lower	Average Upper Elevation	SD Upper
			Elevation (m, CRD)			
0–74	Herbaceous	5	1.16	0.52	3.00	0.33
	Shrub	5	2.22	0.48	3.29	0.25
	Tree (PISI)	4	2.44	0.54	4.31	0.95
75–235	Herbaceous	3	1.73	1.03	3.89	1.27
	Shrub	3	2.31	0.61	3.91	1.54
	Tree (POBA/FRLA)	2	2.40	0.83	4.37	1.73

3.2 Reference and Restoration Site Comparison

We compared reference sites to restoration sites for several metrics, including accretion rates, elevation, hydrology, temperature, vegetation, and channel morphology. The results presented in Section 3.1 were instrumental in conducting the comparison of restoration to reference sites. Based on the location of the restoration sites, we were able to determine the appropriate reference sites using the hydro-vegetation zones as a guide (Table 3.5). In hydro-vegetation zone 1, we also determined the appropriate reference sites based on whether the restoration site was located in a tributary or along the mainstem. The SRD and ML sites were the exception because they are sites that were planted with riparian forested wetland species, for which the hydro-vegetation zones do not apply because they were developed based on extensive sampling of emergent marshes.[1] The forested reference sites in zone 1 occur downstream of rkm 75 and are dominated by Sitka spruce (PISI).

Table 3.5. Restoration sites and the reference sites within the hydro-vegetation zones.

Zone	Restoration Site	Reference Sites
1 (Tributary)	FC, WA, KF, DE	Forest References: CCS SRS KIS SSS Marsh References: FCB HIB CSM GIM
1 (Mainstem)	VS	CHM TBB LCM SRM MSC
2	TI, CI	KIB WIM RIM JIC WHM WAC CRM GUC LI2
4	HR	SBM SCM DMI WRC CLM CS
NA	SRD, ML	SRR CCR GCR

[1] The reference sites for this habitat type (i.e., riparian forested wetland dominated by cottonwood [POBA] and ash [FRLA]) occur starting at approximately rkm 75 and include CCR, GCR, and SRR (Sandy River Reference) sites. The SRR reference site was monitored as part of the ML and SRD restoration planting and was not part of the original Reference Site study.

3.2.1 Sediment Accretion Rate

Sediment accretion rates in the reference sites vary across the estuary from −1.5 to 2.5 cm/year, with the majority of sites having rates between 0.0 and 1.5 cm/year (Figure 3.8). Sites that fall outside this range could be affected by local conditions or possibly single-year events. The most extreme anomaly is the nearly 8-cm erosion seen at the Sand Island site (SIM) located at rkm 211. One explanation for this erosion is that the site is adjacent to the last remaining unstabilized dune area in the lower Columbia River (as described by Christy and Putera 1993), which may cause significant sedimentation and erosion at the site.

Accretion rates at the restoration sites varied spatially and temporally compared to the reference sites. The restoration sites located in the Grays River watershed (KF and DE) tended to have higher accretion rates than the reference sites in second and third years following the restoration action (Figure 3.9). In contrast, the FC site had very low accretion rates. This site is located in the Lewis and Clark watershed, but so is the FCB reference site which had a higher accretion rate, indicating that low sediment source may not be the reason for the low rates at the FC site.

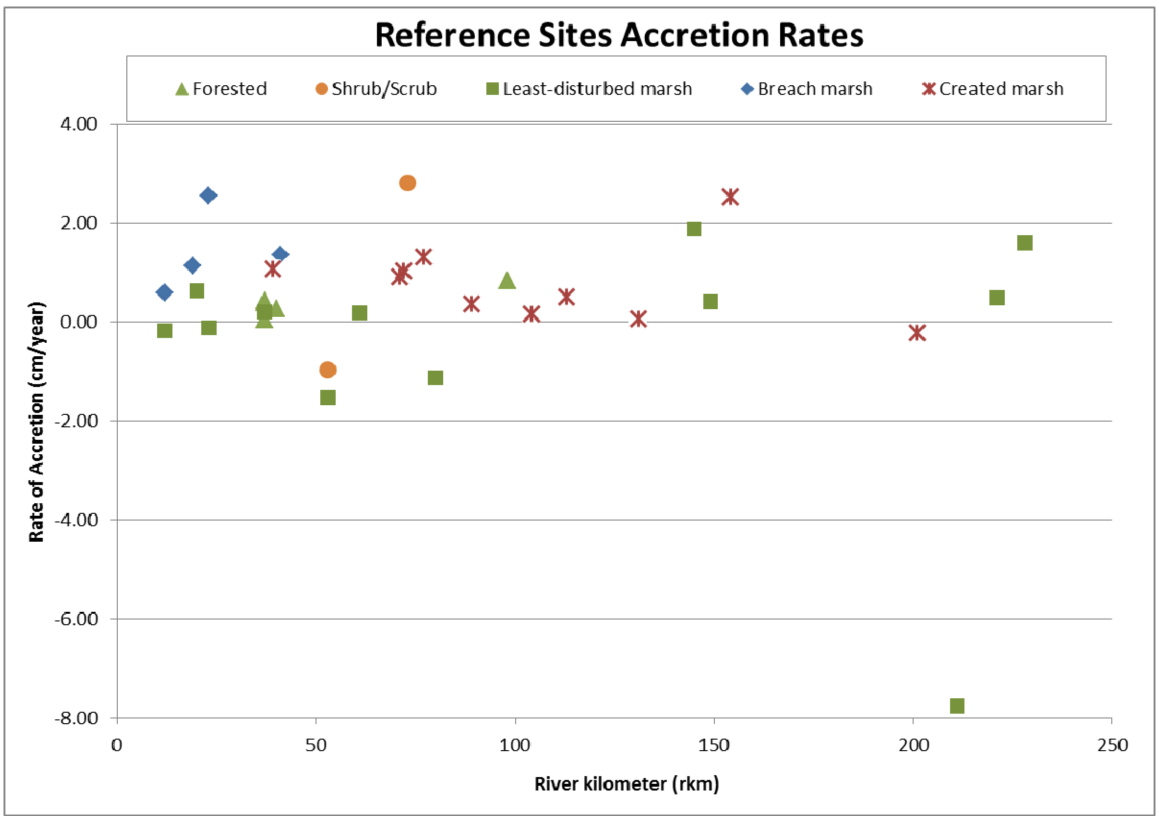


Figure 3.8. Annual accretion rates (cm/year) for all reference sites measured in the estuary as part of this study.

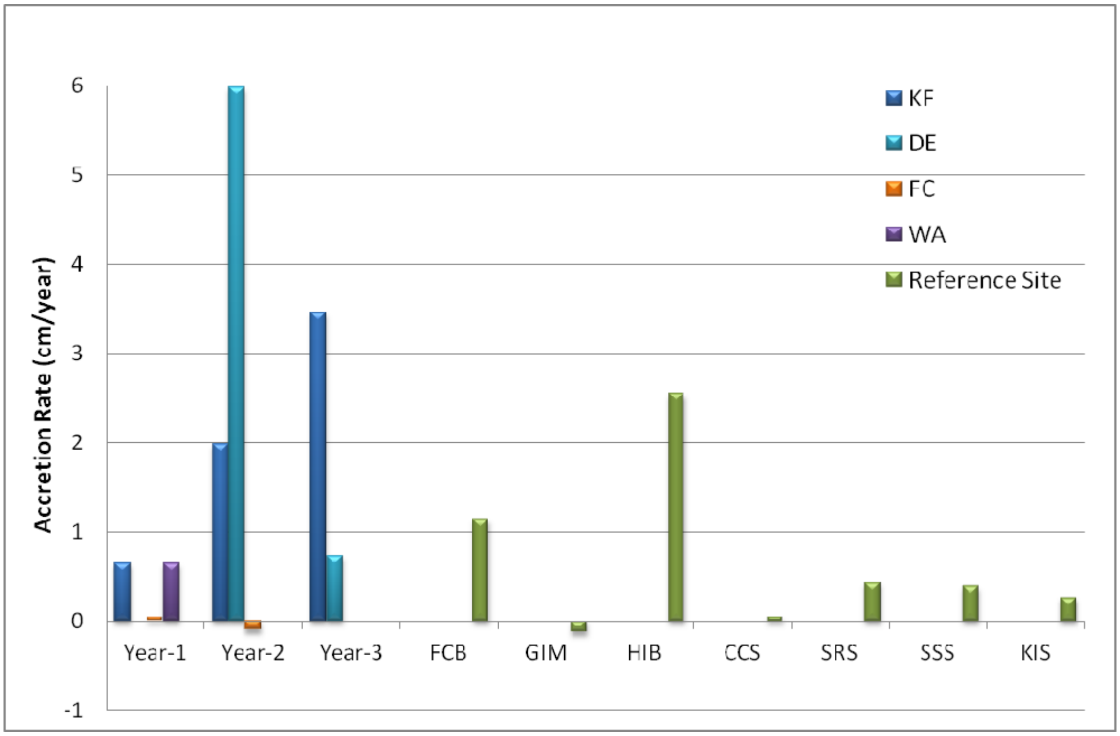


Figure 3.9. Annual accretion and/or erosion rates for the years following the restoration action at four tributary restoration sites compared to reference sites in hydro-vegetation zone 1. The codes on the x-axis represent the reference sites. Note that the four sites on the right end of the axis are forested sites with higher elevations and therefore lower expected accretion rates.

Accretion rates at VS were very high in the second year after restoration, compared to the reference sites. However, the rate declined in the following year, indicating a potential problem with the natural accretion process at this site (Figure 3.10a). In contrast, the accretion rate at CI steadily increased each year and was similar to the majority of the reference sites (Figure 3.10b). Likely, some interannual variability is contributing to the differences in the reference because most sites were measured for only one year and not always the same year.

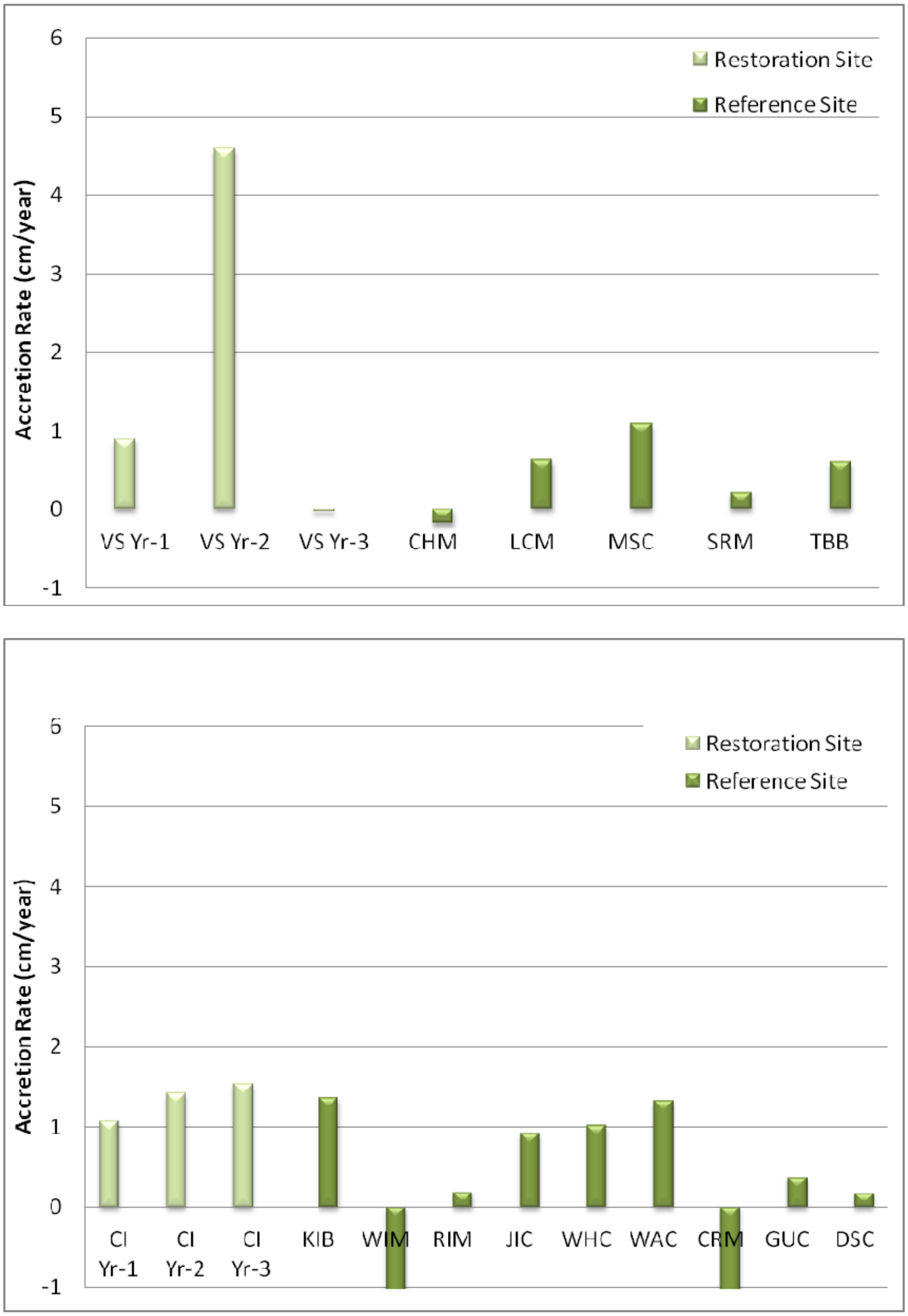
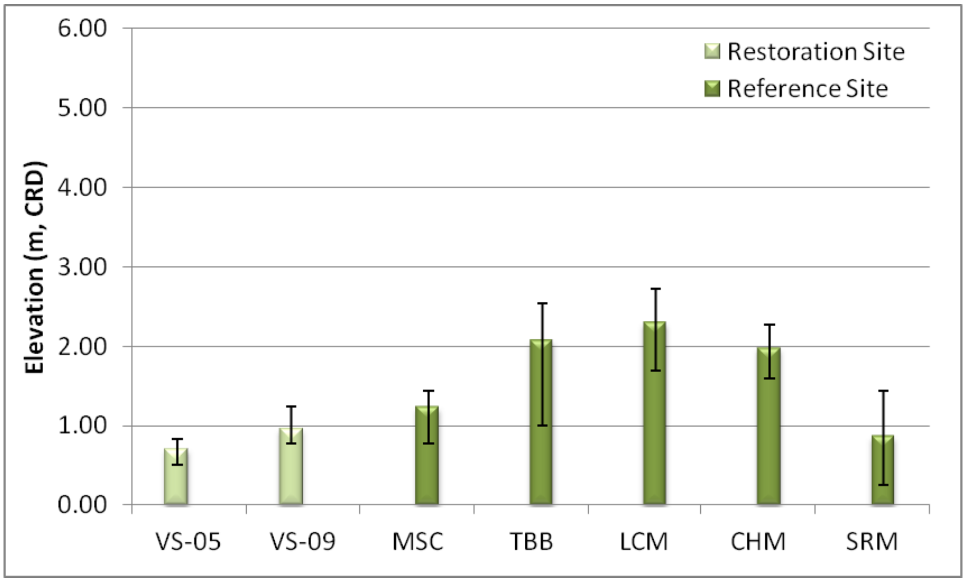


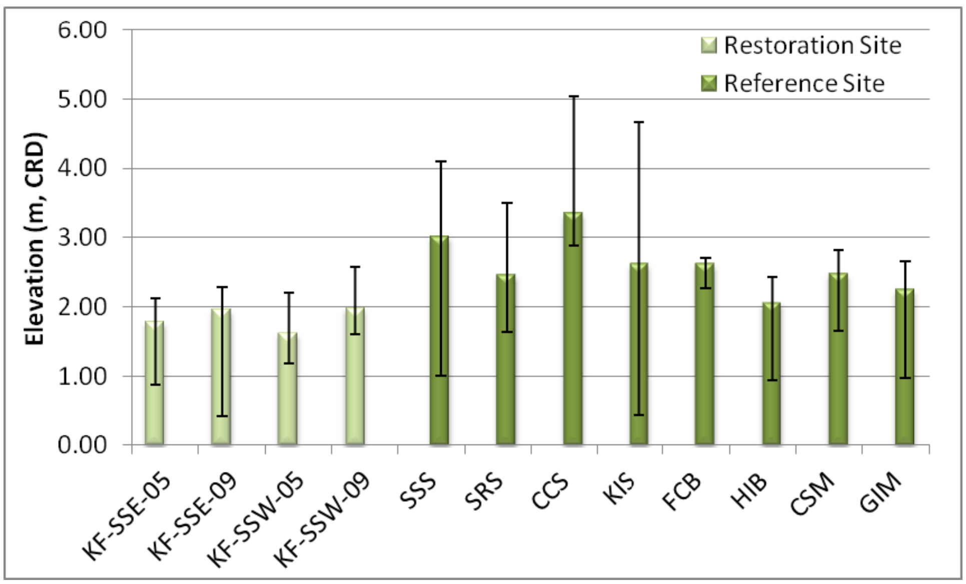
Figure 3.10. Annual accretion and/or erosion rates for all restoration sites in a) Vera Slough (VS) and b) Crims Island (CI) compared to reference sites in the respective hydro-vegetation zones.

3.2.2 Elevation

Elevation at the restoration sites that had been diked (VS and KF) was somewhat lower than that of the selected reference sites (Figure 3.11). The VS site elevation was most similar to SRM, the lowest marsh reference site measured, indicating that given enough time, the VS site will likely colonize with low-elevation marsh species. The average elevation at KF was lower than the average elevation at all other tributary reference sites except HIB, another previously diked and breached site. The highest average elevations were measured at the forested reference sites (SSS, SRS, CCS, and KIS), as would be expected for a wetland farther along the successional gradient in the LCRE (Fox et al. 1984).



a)



b)

Figure 3.11. Average elevation for the vegetation sample area at restoration sites a) Vera Slough, b) Kandoll Farm, and c) Crims Island compared to the average elevation of the reference site sample areas in each hydro-vegetation zone. Error bars represent the minimum and maximum elevations at the sample area.

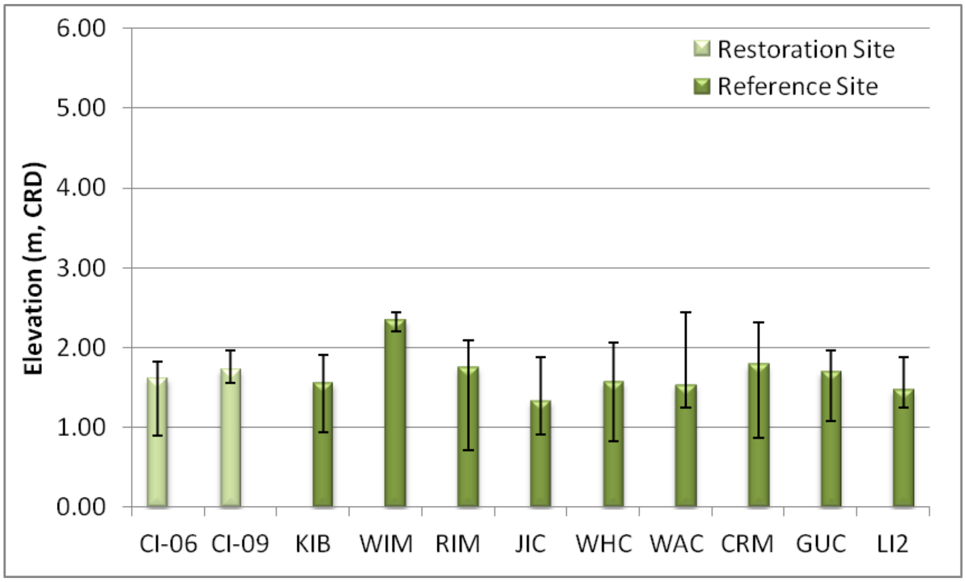
c) 

Figure 3.11. (contd)

The greater elevation range at KF in 2009 and the opposite trend at CI could be attributable to the different restoration actions taken at these sites. The topography at KF is likely becoming more channelized over time because the daily tidal flows are re-establishing the dendritic channel patterns that were lost from many years of agricultural practices at the site (see Diefenderfer et al. 2008). In contrast, CI was excavated from a wet pasture, with created channels. The first year after restoration (2006), remnant hummocks and swales were observed from the heavy equipment that evened out by 2009. Small channel development was noted at the site (Borde et al. 2008b); however, it was not in the area of the vegetation sampling.

3.2.3 Hydrology

Kandoll Farm SEV was variable between years; however, the range was within that of the marsh reference sites. When compared to the forested reference sites, the SEV at the restoration site is generally higher than at the reference sites. Again, variability between years is evident, with the restoration site having the lowest SEV in 2006–2007. Within the same year, some comparisons can be made between the sites. In 2007–2008, the KF restoration site had the highest SEV and the other three reference sites with data from that year were lower. The CI restoration site had SEVs similar to the reference sites within the same hydro-vegetation zone.

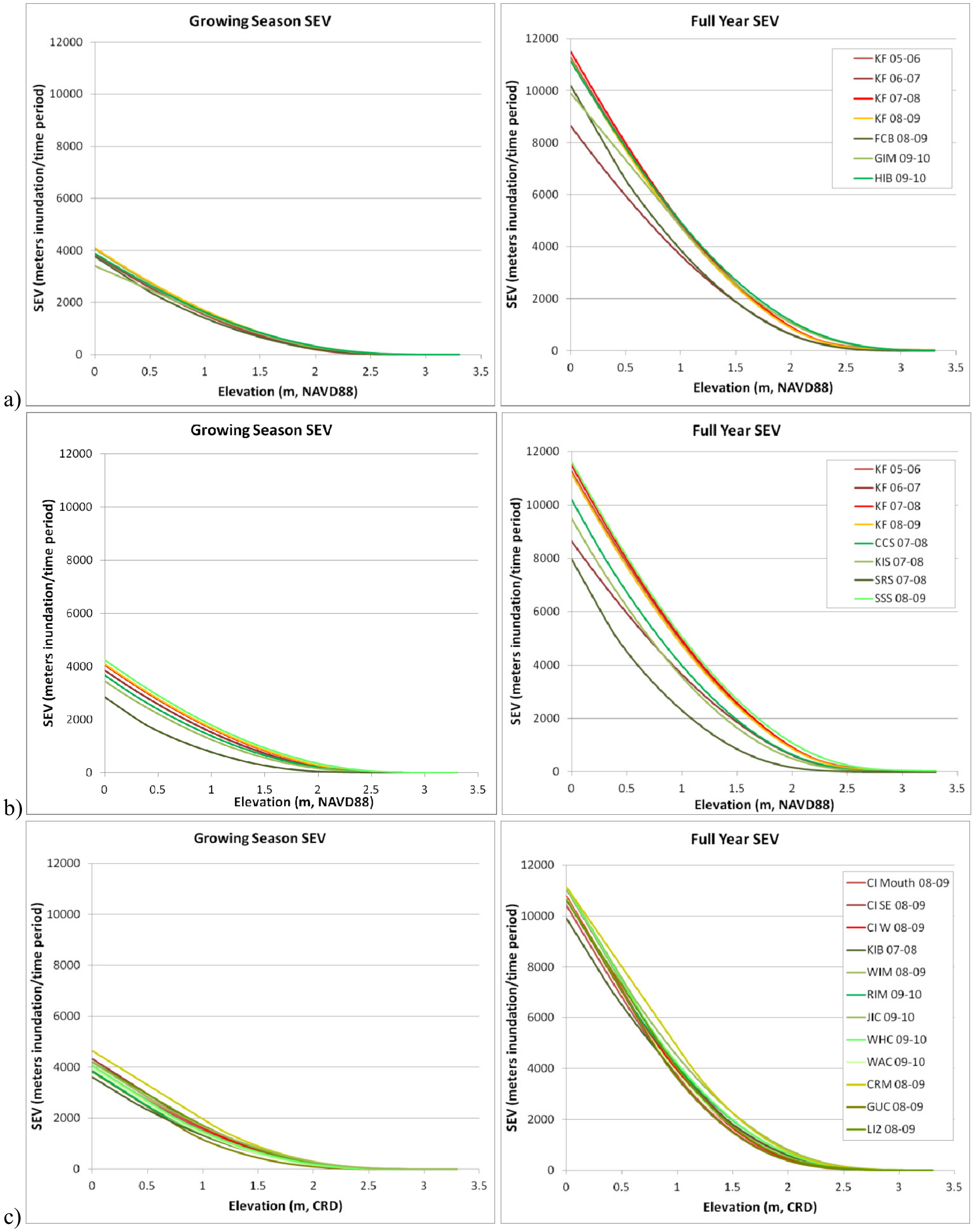


Figure 3.12. Sum exceedance value (SEV) as calculated for the growing season and for a full year at a) Kandoll Farm compared to the tributary marsh reference sites in hydro-vegetation zone 1; b) Kandoll Farm compared to forested wetland reference sites in hydro-vegetation zone 1; and c) Crims Island compared to the marsh reference sites in hydro-vegetation zone 2.

3.2.4 Temperature

In most locations, the water temperature at the reference sites and restoration sites followed similar patterns during the period of peak juvenile Chinook migration from March through July (see Appendix A for graphs showing the temperature patterns during this time period). The seven-day running average of the daily maximum (7DADmax) is one way to evaluate high-temperature patterns and to determine the potential detrimental effect of prolonged high temperature on salmonids. The WADOE has established a criterion of 17.5°C as the highest 7DADmax for favorable rearing and migration conditions. Of the 25 reference sites, all of them exceeded the WADOE thermal criterion sometime from May through July. Similarly, all of the of restoration sites exceeded the WADOE thermal criterion from May through July except a couple sensors located in perennial creeks at the Mirror Lake site.

The date of first exceedance of this criterion is a means of estimating the time at which site temperatures may become unfavorable (Table 3.6–Twelve sensors were deployed at the Mirror Lake (ML) site: along the wetland channel and in the two creeks feeding into the wetland (**Error! Not a valid bookmark self-reference.**). For comparison, at this site we used data from the CR main channel at Camas in addition to the single appropriate reference site. The temperature in the ML creeks stayed below the WADOE criterion throughout the summer in 2010 while most of the wetland channels exceeded the criterion by late June. The reference temperatures were found to exceed the criterion 11 days later than the temperatures in the wetland channel at ML, indicating that the wetland channels are warming sooner than the main channel.

We observed in this analysis that in general the tributary sites remain cooler a little longer than sites located on the main stem of the river. In addition, shade at forested sites appeared to decrease temperatures in some cases, though not where the sites were close to the shallow waters of Grays Bay. Deep channels, such as those found at the mouth of the CI restoration site, also produce a later date of the temperature criterion exceedance. Site-specific features such as logs may also have reduced temperatures at the location of some sensors (e.g., Whites Island, WHC), indicating that such areas could potentially provide thermal refugia for juvenile salmonids.

Table 3.12). The WADOE temperature criterion was generally exceeded in the reference sites within a few days of when it was exceeded at the restoration sites, with a few exceptions. Tenasillahee (TI) was very similar to the Karlson Island previously diked site (KIB) in 2008 (Table 3.9). However, the temperatures were lower than most other reference sites in 2009. The WADOE criterion was exceeded 33 days later at TI in 2009 than the earliest reference site exceedance. The earlier exceedances at the reference sites were from sites located 30–40 km upstream, while the temperature criterion was exceeded only 5 days earlier at the Welch Island reference site (WIM) located a few river kilometers downstream of TI, so higher temperatures may be associated with location in the river. The cooler temperatures at TI could also perhaps be due to the location of the temperature sensor in a deeper channel than those at the reference sites. Ennis (2009) does not give channel depth at the location of the TI sensor, but the channel in general appears to be larger than the reference channels. See site maps in Appendix C for locations of depth/temperature sensors at the reference sites.

Table 3.6. Date of first WADOE 7-day average maximum temperature exceedance at Vera Slough (VS) and the associated marsh reference sites in hydro-vegetation zone 1.

Year	rkm	2008	2009

VS	19	ND	13 May
CHM	12	ND	29 April
SRM	37	13 May	ND

Table 3.7. Date of first WADOE 7-day average maximum temperature exceedance at Kandoll Farm (KF) and Fort Clatsop (FC) restoration sites and the associated marsh tributary reference sites in hydro-vegetation zone 1.

Site	rkm	2006	2007	2008	2009	2010
FC	19[(a)]			15 May		
KF	37[(a)]	15 May	31 May	26 June	29 May	ND
FCB	19[(a)]				17 May	
GIM	23[(a)]					23 June
HIB	23[(a)]					23 June
WAB	23[(a)]				15 May	
WAM	23[(a)]				14 May	

(a) These sites are located up tributaries. In these cases, the distance from the Columbia River mouth represents the distance to the mouth of the tributary, not the distance up the tributary

Table 3.8. Date of first WADOE 7-day average maximum temperature exceedance at Kandoll Farm (KF) and Fort Clatsop (FC) restoration sites and the associated forested reference sites in hydro-vegetation zone 1.

Site	rkm	2006	2007	2008	2009
FC	19[(a)]			15 May	
KF	37[(a)]	15 May	31 May	26 June	29 May
SSS	37[(a)]			27 June	31 May
CCS	37[(a)]			17 May	
KIS	40			23 June	
SRS	37[(a)]			14 May	

(a) These sites are located up tributaries. In these cases, the distance from the Columbia River mouth represents the distance to the mouth of the tributary, not the distance up the tributary

Table 3.9. Date of first WADOE 7-day average maximum temperature exceedance at Tenasillahe (TI) and the associated reference sites. Note: TI tide gates were replaced in August 2007.

Site	EM Zone	rkm	2006	2007	2008	2009	2010
TI	2	57	4 May	11 May	14 May	19 May	ND
KIB	2	41			13 May		
WIM	2	53				14 May	
RIM	2	61					4 May
BSM	2	62					24 June
WHC	2	72					20 June
WAC	2	77					5 May
CRM	2	80				17 April	
LI2	2	100				21 April	
DSC	2	104				1 June	27 June

The HR site had the earliest temperature criterion exceedance of all the restoration or reference sites (Table 3.10). The site is located up a series of backwater sloughs and may therefore have reduced flows and relative to sites closer to the mainstem. However, the CLM reference site is located approximately 6 km up a slough and while the temperatures exceeded the criterion in early April, the date was weeks later than at the HR site, indicating that some other factor may be causing the higher temperatures at HR.

Table 3.10. Date of first WADOE 7-day average maximum temperature exceedance at Hogan Ranch (HR) and the associated reference sites in hydro-vegetation zone 4.

Site	rkm	2009	2010
HR	146	6 April	17 March
SBM	143		11 May
CS1	149	14 May	6 May
CLM	145		12 April
SSC	154		8 April

Two sites had multiple sensors deployed where differences were observed within the site. Four sensors were deployed at the restoration site at Crims Island, three in upper portions of the excavated channels and one near the mouth of the main channel (Table 3.11). The sensor at the mouth remained below the WADOE criterion longer than the other three in 2008 by 6 to 8 days, likely because it was placed deeper than the other sensors. In 2009, the temperature at the mouth was similar to that on the west side channel, and both remained below the criterion for 15 days longer than the temperature in the southeast side channel (the northeast side channel sensor was removed in 2009).

Table 3.11. Date of first WADOE 7-day average maximum temperature exceedance at Crims Island (CI) restoration site and the associated reference sites in hydro-vegetation zone 2.

Site	rkm	2008	2009	2010
CI-M	90	24 June	29 May	ND
CI-WC		14 May	28 May	ND
CI-SE		15 May	19 April[b]	ND
CI-NE		28 April[a]	ND	ND
KIB	41	13 May		
WIM	53		14 May	
RIM	61			4 May
BSM	62			24 June
WHC	72			20 June
WAC	77			5 May
CRM	80		17 April	
LI2	100		21 April	
DSC	104		1 June	27 June

(a) Exceeded for one day on 28 April, then not again until 13 May.
(b) Exceeded for two days on 19 April, then not again until 14 May.

Twelve sensors were deployed at the Mirror Lake (ML) site: along the wetland channel and in the two creeks feeding into the wetland (**Error! Not a valid bookmark self-reference.**). For comparison, at this site we used data from the CR main channel at Camas in addition to the single appropriate reference site. The temperature in the ML creeks stayed below the WADOE criterion throughout the summer in 2010 while most of the wetland channels exceeded the criterion by late June. The reference temperatures were found to exceed the criterion 11 days later than the temperatures in the wetland channel at ML, indicating that the wetland channels are warming sooner than the main channel.

We observed in this analysis that in general the tributary sites remain cooler a little longer than sites located on the main stem of the river. In addition, shade at forested sites appeared to decrease temperatures in some cases, though not where the sites were close to the shallow waters of Grays Bay. Deep channels, such as those found at the mouth of the CI restoration site, also produce a later date of the temperature criterion exceedance. Site-specific features such as logs may also have reduced temperatures at the location of some sensors (e.g., Whites Island, WHC), indicating that such areas could potentially provide thermal refugia for juvenile salmonids.

Table 3.12. Date of first WADOE 7-day average maximum temperature exceedance at Mirror Lake (ML) restoration site and the associated reference sites in hydro-vegetation zone 5.

Site	rkm	2010
LC/YC-M	208	ND
LC/YC-2		25 June
LC/YC-3		24 June
LC-LOW		24 June
LC-MID		4 Aug
LC-RR		DNE[a]
YC-ML		15 May[b]
YC-MID		6 July
YC-B		DNE
YC-RR		DNE
WRM	195	6 July
Camas	195	5 July

(a) DNE – Did not exceed the temperature criterion during the period of March through July.
(b) Exceeded for 2 days on 15 May then not again until 25 June.

3.2.5 Vegetation

3.2.5.1 Bivariate Analysis

In hydro-vegetation zone 1, we compared average percentage cover of *Typha* spp. to *Carex* spp for the bivariate analysis. The results indicate that Vera Slough (VS) had higher cover of *Typha* and *Carex* compared to the reference sites in the first two years of monitoring, followed by lower cover of both species by 2009 (Figure 3.13a). This trend is likely due the increase in salinity and inundation following the restoration action resulting in a decrease in the freshwater species of sedge (*Carex obnupta*) and an overall decline in vegetation cover. At the tributary sites in hydro-vegetation zone 1, the results show that *Typha* does not have high cover at any of the restoration or reference sites. However, *Carex* was present at a cover of at least 10% to 50% at the reference sites, while the restoration sites had less than 10% *Carex* cover (Figure 3.13b).

We compared the cover of two native species, common spike rush (*Eleocharis palustris*; ELPA) and wapato (*Sagittaria latifolia*; SALA), at sites in the tidal freshwater areas of the LCRE. At the two restoration sites, there was lower cover of both species in the earliest years post-restoration than at most of the reference sites (Figure 3.14). However, both sites trended toward higher cover of the native species in the following monitoring years. The exception is at the HR site where cover of the two species increased in 2008, perhaps due to higher water levels that year, then declined again in 2010.

a)

b)

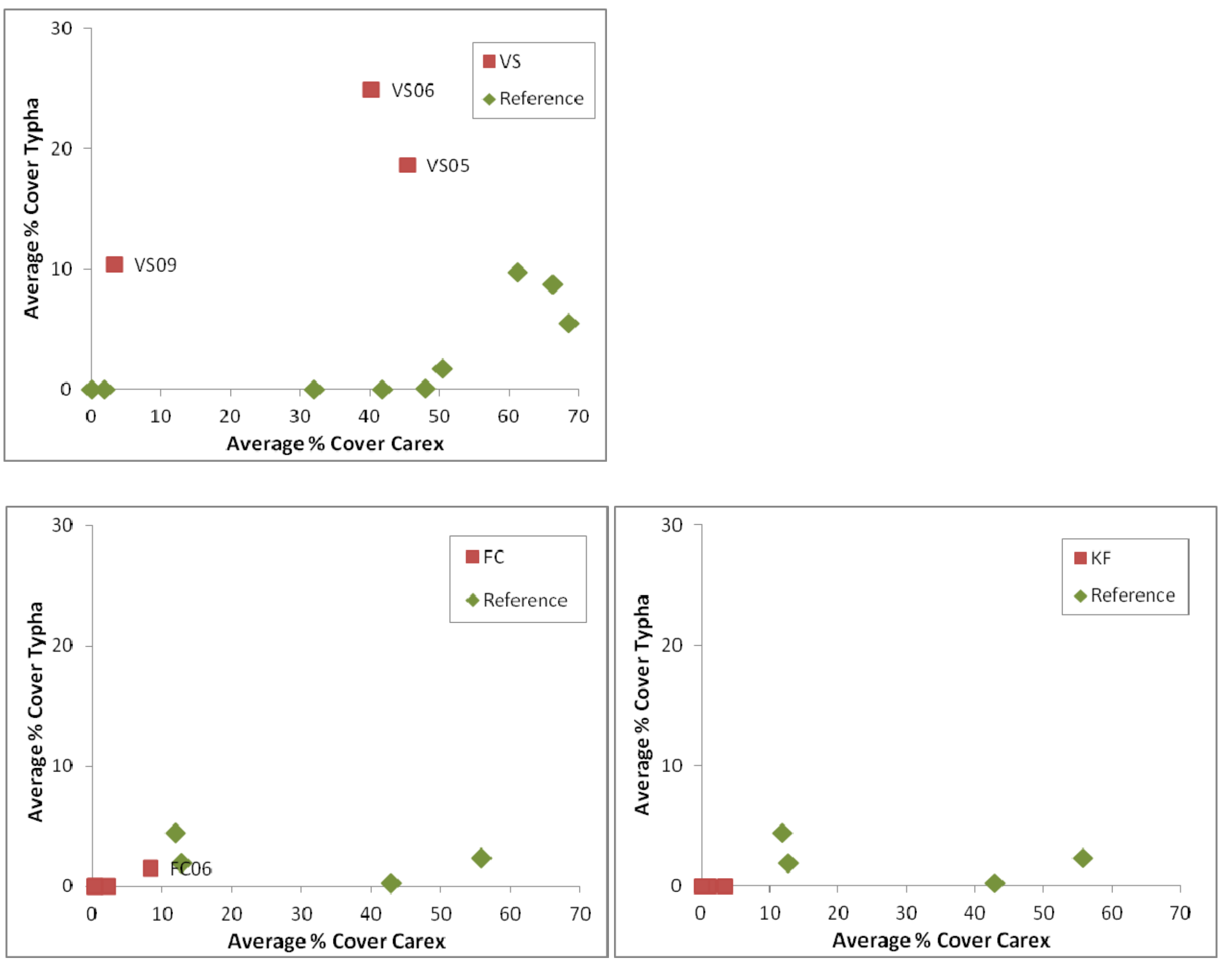


Figure 3.13. Bivariate analysis of average percentage cover of *Carex* spp. relative to *Typha* spp. at restoration sites in hydro-vegetation zone 1 compared to reference sites in a) the mainstem and b) tributaries. Each point represents the average cover from 1-year at a site.

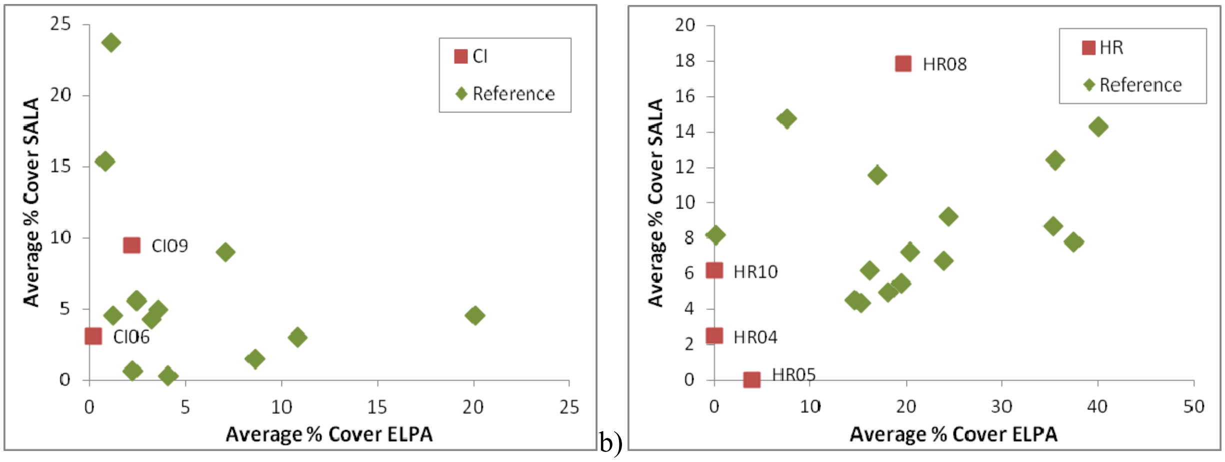
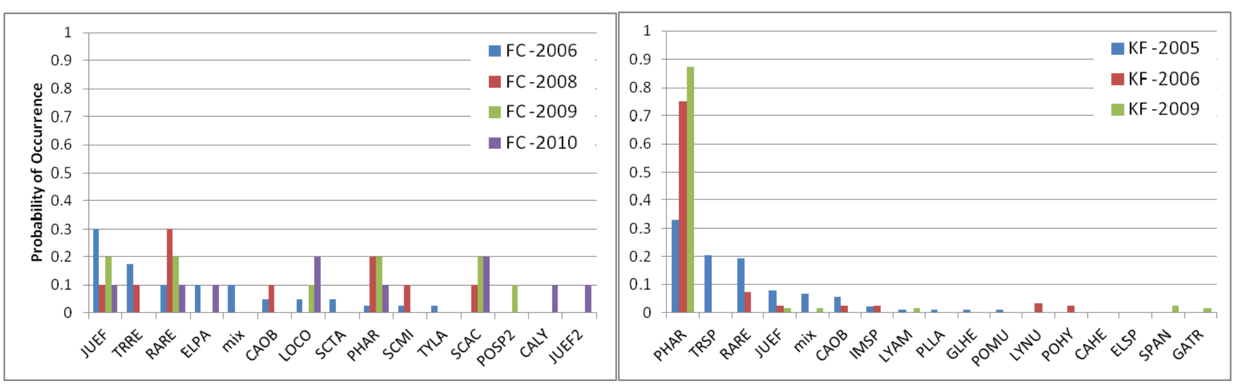


Figure 3.14. Bivariate analysis of average percent cover of *Eleocharis palustris* (ELPA) relative to *Sagittaria latifolia* (SALA) at restoration sites compared to reference sites in a) hydro-vegetation zone 2 and b) hydro-vegetation zone 4.

3.2.5.2 Probability of Occurrence

The probability of occurrence graphs allow us to look at the change in species occurrence over time at a restoration site and also to compare the restoration site to the probability of occurrence at the reference sites in the same hydro-vegetation zone. In general, the species assemblages at the restoration sites were different from those at the reference sites, particularly in hydro-vegetation zone 1 (Figure 3.15 and Figure 3.16). The vegetation species assemblages at the restoration and reference sites above hydro-vegetation zone 1 (and at KF in zone 1, which is above the salinity zone) have a high probability of occurrence of reed canary-grass (*Phalaris arundinacea*; PHAR) (Figure 3.17 and Figure 3.18). This similarity between the reference and restoration sites is not necessarily desirable because reed canary-grass is a non-native, invasive species. For more information regarding the occurrence and elevations of reed canary-grass, see Borde et al. (2012).



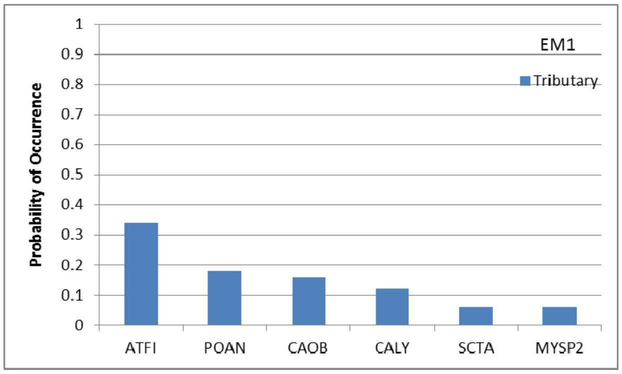


Figure 3.15. The probability of occurrence of plant species at restoration sites Fort Clatsop and Kandoll Farm (top) compared to the probability of occurrence of the dominant species in the least-disturbed marsh tributary reference sites in hydro-vegetation zone 1 (bottom).

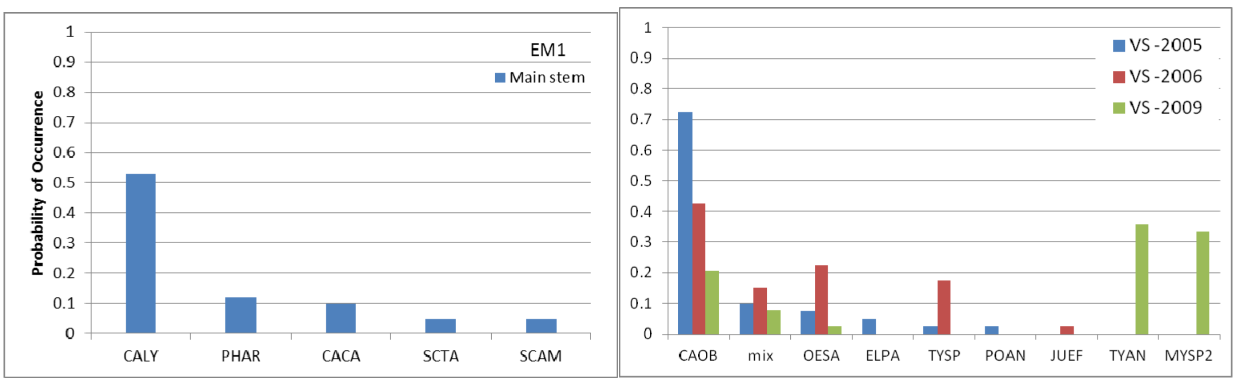


Figure 3.16. The probability of occurrence of plant species at restoration sites Vera Slough (right) compared to the probability of occurrence of the dominant species in the least-disturbed marsh mainstem reference sites in hydro-vegetation zone 1 (left).

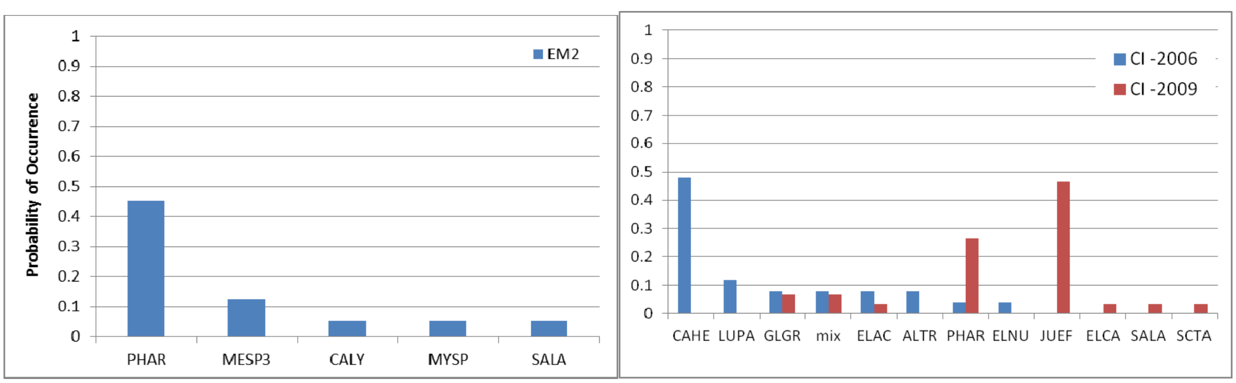


Figure 3.17. The probability of occurrence of plant species at restoration site Crims Island compared to the probability of occurrence of the dominant species in the least-disturbed marsh reference sites in hydro-vegetation zone 2.

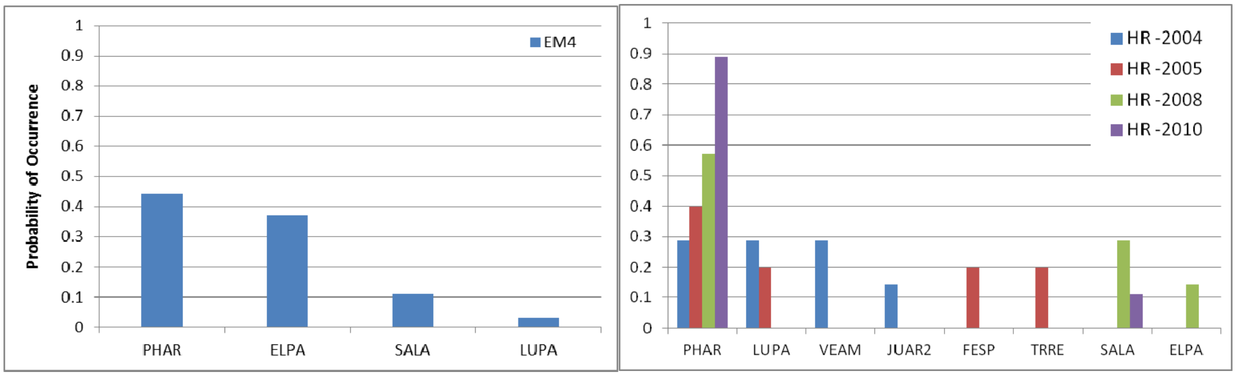


Figure 3.18. The probability of occurrence of plant species at restoration site Hogan Ranch compared to the probability of occurrence of the dominant species in the least-disturbed marsh reference sites in hydro-vegetation zone 4.

3.2.5.3 Similarity Index

The similarity index is a means of comparing the vegetation species composition and cover between sites or between years. In general, we found that most of the vegetation species assemblages at the restoration sites were less than 50% similar to those found at the reference sites (Table 3.13 through Table 3.16, Table 3.18, and Table 3.20). Exceptions include Hogan Ranch (HR), where the site was greater than 50% similar to many of the reference sites in most years and greater than 75% similar in 2008 (Table 3.17). Likewise the sites that were planted with tree and shrub species, Mirror Lake (ML) and the Sandy River Delta (SRD), had species assemblages that were more than 50% similar to the reference sites for the tree species (Table 3.19 and Table 3.21); however, this represents trees with similar stem density and does not account for the maturity of trees at reference sites compared to plantings.

A comparison between years at restoration sites shows there to be a decreasing similarity in the vegetation species assemblages over time. This trend indicates that each assemblage was changing from initial samplings, which is the expected outcome port-restoration. The further expectation would be that the restoration sites would eventually trend toward a greater similarity to the reference sites, but this can take many years (Thom et al. 2002).

An assessment of the vegetation similarity between multiple years at reference sites indicates that inter-annual variability occurs at these sites. At Cunningham Lake, the similarity between years ranged from 63% to 84%. Likewise, at Campbell Slough the range was between 73% and 91%. Presumably, this variability is associated with the hydrologic variability noted earlier; however, local disturbances can have an effect as well. For example, cows inadvertently gained access to the Campbell Slough site in 2007, and the similarity to other years dropped to 65%. In another study, Thom et al. (2002) found that the similarity between years in a reference site ranged from 59% to 84%. This natural variability at reference sites is important to consider when evaluating restoration trends.

One additional factor that became evident during this analysis is the low similarity of vegetation species assemblages between some of the reference sites within the same hydro-vegetation zone. In hydro-vegetation zone 2, the high species diversity may provide one explanation for the low similarity between sites (Table 3.16). Another possible explanation for dissimilarity between sites could be disturbances affecting the reference sites. We hypothesize that sites with higher levels of disturbance are less similar to other reference sites in the same hydro-vegetation zone. For example, in hydro-vegetation zone 4, the dissimilarity of WRC to all other reference sites could likely be explained by the location of the site in an urban setting and the reduced connectivity to the river due to sediment transport of dredged material across the mouth of the site (Table 3.17). Further assessment of historical and recent disturbances at the sites would help to prove or disprove this hypothesis.

Table 3.13. Similarity of the herbaceous strata between the restoration sites Kandoll Farm and Fort Clatsop and tributary emergent marsh reference sites in hydro-vegetation zone 1. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006). Restoration sites are highlighted in yellow. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CSM7	FCB8	GIM9	HIB9	KF5	KF6	KF9	FC6	FC8	FC9	FC10
CSM7	1.00	0.23	0.11	0.10	0.06	0.06	0.03	0.26	0.06	0.08	0.01
FCB8	0.23	1.00	0.23	0.26	0.23	0.19	0.19	0.26	0.25	0.24	0.20
GIM9	0.11	0.23	1.00	0.30	0.01	0.01	0.03	0.10	0.02	0.06	0.03
HIB9	0.10	0.26	0.30	1.00	0.18	0.19	0.20	0.22	0.24	0.21	0.28
KF5	0.06	0.23	0.01	0.18	1.00	0.55	0.42	0.29	0.49	0.47	0.28
KF6	0.06	0.19	0.01	0.19	0.55	1.00	0.75	0.19	0.38	0.34	0.23
KF9	0.03	0.19	0.03	0.20	0.42	0.75	1.00	0.09	0.27	0.24	0.18
FC6	0.26	0.26	0.10	0.22	0.29	0.19	0.09	1.00	0.53	0.46	0.42
FC8	0.06	0.25	0.02	0.24	0.49	0.38	0.27	0.53	1.00	0.74	0.60
FC9	0.08	0.24	0.06	0.21	0.47	0.34	0.24	0.46	0.74	1.00	0.65
FC10	0.01	0.20	0.03	0.28	0.28	0.23	0.18	0.42	0.60	0.65	1.00

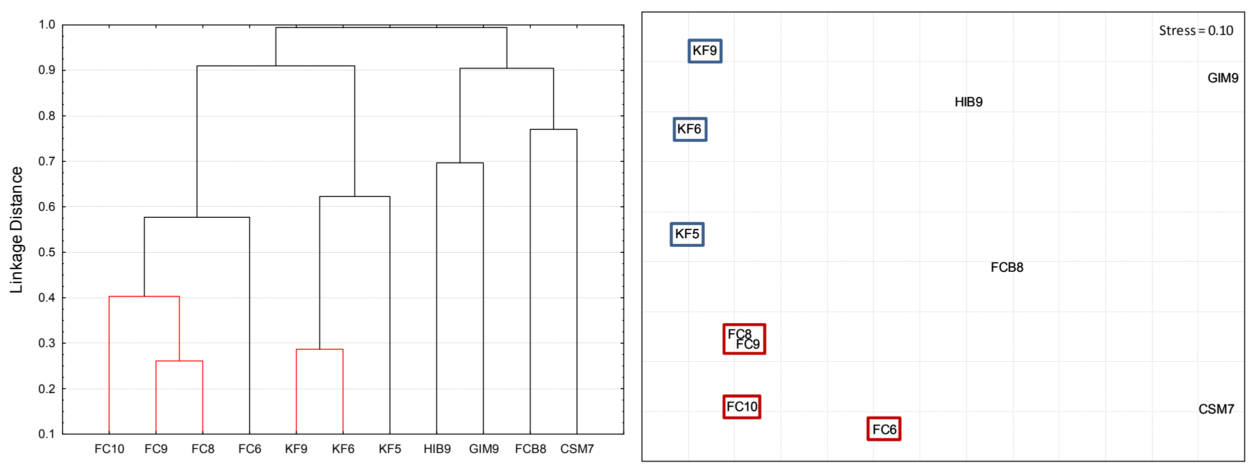


Figure 3.19. Dendrogram (left) and an nMDS plot (right) of the similarity between the restoration sites Fort Clatsop (red boxes) and Kandoll Farm (blue boxes) relative to tributary emergent marsh reference sites in hydro-vegetation zone 1 using complete linkage and Relative Sørensen's similarity measurements. Red lines on the dendrogram represent a similarity greater than 50%. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006).

Table 3.14. Similarity of the herbaceous strata between the restoration sites Kandoll Farm and Fort Clatsop and forested swamp reference sites in hydro-vegetation zone 1. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006). Restoration sites are highlighted in yellow. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CCS7	KIS8	SRS8	SSS9	KF5	KF6	KF9	FC6	FC8	FC9	FC10
CCS7	1.00	0.47	0.63	0.51	0.17	0.16	0.16	0.14	0.10	0.07	0.06
KIS8	0.47	1.00	0.30	0.38	0.08	0.05	0.09	0.04	0.01	0.03	0.03
SRS8	0.63	0.30	1.00	0.44	0.18	0.18	0.19	0.09	0.14	0.12	0.11
SSS9	0.51	0.38	0.44	1.00	0.23	0.20	0.20	0.19	0.15	0.13	0.12
KF5	0.17	0.08	0.18	0.23	1.00	0.55	0.42	0.31	0.51	0.48	0.30
KF6	0.16	0.05	0.18	0.20	0.55	1.00	0.75	0.20	0.39	0.35	0.23
KF9	0.16	0.09	0.19	0.20	0.42	0.75	1.00	0.09	0.27	0.24	0.19
FC6	0.14	0.04	0.09	0.19	0.31	0.20	0.09	1.00	0.53	0.46	0.42
FC8	0.10	0.01	0.14	0.15	0.51	0.39	0.27	0.53	1.00	0.74	0.60
FC9	0.07	0.03	0.12	0.13	0.48	0.35	0.24	0.46	0.74	1.00	0.65
FC10	0.06	0.03	0.11	0.12	0.30	0.23	0.19	0.42	0.60	0.65	1.00

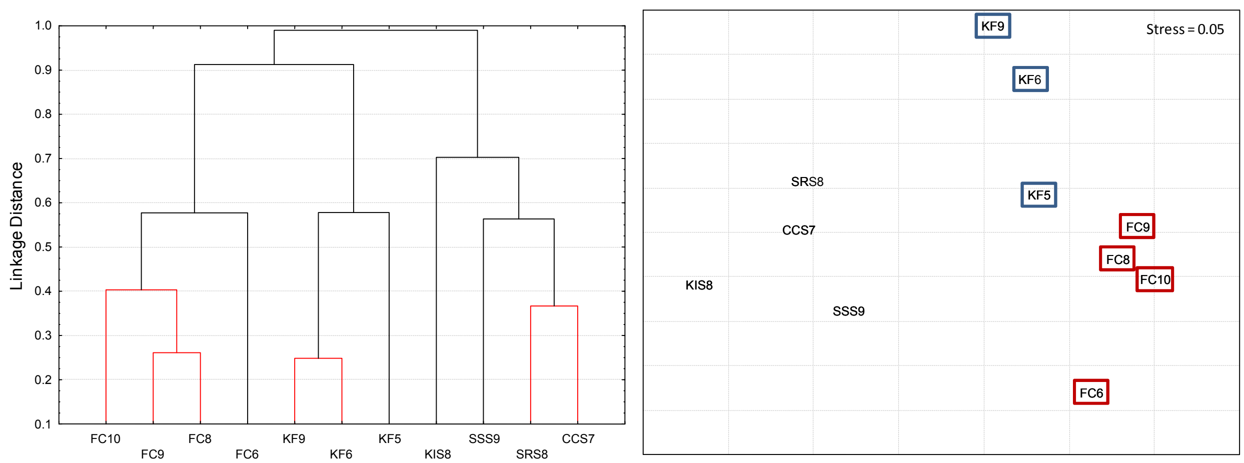


Figure 3.20. Dendrogram (left) and an nMDS plot (right) of the similarity between the restoration sites Kandoll Farm and Fort Clatsop and forested swamp reference sites using complete linkage and relative Sørensen's similarity measurement. Red lines on the dendrogram represent a similarity greater than 50%. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006).

Table 3.15. Similarity of the herbaceous strata between the restoration site Vera Slough and mainstem emergent marsh reference sites in hydro-vegetation zone 1. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006). Restoration sites are highlighted in yellow and multiple years for a reference site are highlighted in orange. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CHM-H9	CHM-L9	LCM5	LCM6	LCM9	MSC9	SRM-H8	SRM-L8	TBB8	VS5	VS6	VS9
CHM-H9	1.00	0.64	0.31	0.32	0.31	0.15	0.33	0.11	0.56	0.01	0.00	0.00
CHM-L9	0.64	1.00	0.37	0.38	0.37	0.16	0.38	0.14	0.54	0.01	0.00	0.00
LCM5	0.31	0.37	1.00	0.90	0.85	0.00	0.62	0.11	0.59	0.19	0.16	0.05
LCM6	0.32	0.38	0.90	1.00	0.84	0.02	0.59	0.12	0.58	0.11	0.09	0.03
LCM9	0.31	0.37	0.85	0.84	1.00	0.00	0.63	0.15	0.59	0.12	0.10	0.06
MSC9	0.15	0.16	0.00	0.02	0.00	1.00	0.01	0.13	0.01	0.02	0.00	0.00
SRM-H8	0.33	0.38	0.62	0.59	0.63	0.01	1.00	0.14	0.48	0.18	0.15	0.08
SRM-L8	0.11	0.14	0.11	0.12	0.15	0.13	0.14	1.00	0.04	0.06	0.01	0.00
TBB8	0.56	0.54	0.59	0.58	0.59	0.01	0.48	0.04	1.00	0.08	0.02	0.00
VS5	0.01	0.01	0.19	0.11	0.12	0.02	0.18	0.06	0.08	1.00	0.78	0.22
VS6	0.00	0.00	0.16	0.09	0.10	0.00	0.15	0.01	0.02	0.78	1.00	0.22
VS9	0.00	0.00	0.05	0.03	0.06	0.00	0.08	0.00	0.00	0.22	0.22	1.00

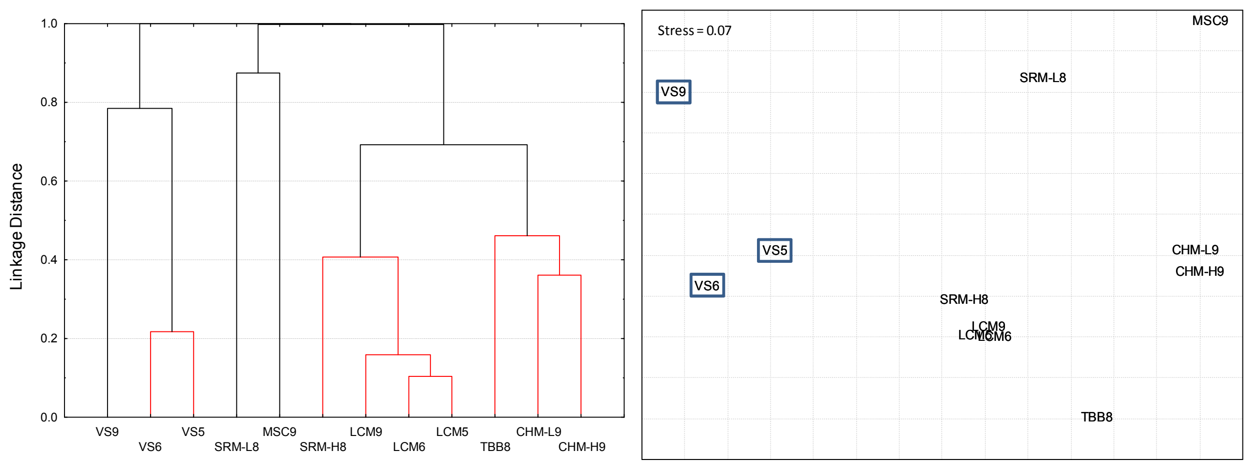


Figure 3.21. Dendrogram (left) and an nMDS plot (right) of the similarity between the restoration site Vera Slough relative to selected reference sites using complete linkage and relative Sørensen's similarity. Red lines on the dendrogram represent a similarity greater than 50%. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006).

Table 3.16. Similarity of the herbaceous strata between the restoration site Crims Island and mainstem emergent marsh reference sites in hydro-vegetation zone 2. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006). Restoration sites are highlighted in yellow and multiple years for a reference site are highlighted in orange. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CRM9	GUC6	GUC9	JIC10	KIB8	LI29	RIM9	WAC10	WHC9	WHC10	WIM8	CI6	CI9
CRM9	1.00	0.22	0.22	0.42	0.31	0.33	0.47	0.37	0.65	0.54	0.15	0.14	0.45
GUC6	0.22	1.00	0.52	0.20	0.33	0.16	0.11	0.12	0.21	0.09	0.18	0.11	0.12
GUC9	0.22	0.52	1.00	0.18	0.43	0.12	0.13	0.13	0.22	0.09	0.19	0.08	0.12
JIC10	0.42	0.20	0.18	1.00	0.29	0.29	0.49	0.49	0.46	0.46	0.14	0.23	0.41
KIB8	0.31	0.33	0.43	0.29	1.00	0.20	0.23	0.22	0.34	0.24	0.19	0.13	0.24
LI29	0.33	0.16	0.12	0.29	0.20	1.00	0.20	0.23	0.22	0.21	0.10	0.12	0.27
RIM9	0.47	0.11	0.13	0.49	0.23	0.20	1.00	0.36	0.60	0.54	0.16	0.09	0.33
WAC10	0.37	0.12	0.13	0.49	0.22	0.23	0.36	1.00	0.41	0.44	0.11	0.17	0.37
WHC9	0.65	0.21	0.22	0.46	0.34	0.22	0.60	0.41	1.00	0.72	0.16	0.13	0.38
WHC10	0.54	0.09	0.09	0.46	0.24	0.21	0.54	0.44	0.72	1.00	0.22	0.16	0.38
WIM8	0.15	0.18	0.19	0.14	0.19	0.10	0.16	0.11	0.16	0.22	1.00	0.10	0.13
CI6	0.14	0.11	0.08	0.23	0.13	0.12	0.09	0.17	0.13	0.16	0.10	1.00	0.30
CI9	0.45	0.12	0.12	0.41	0.24	0.27	0.33	0.37	0.38	0.38	0.13	0.30	1.00

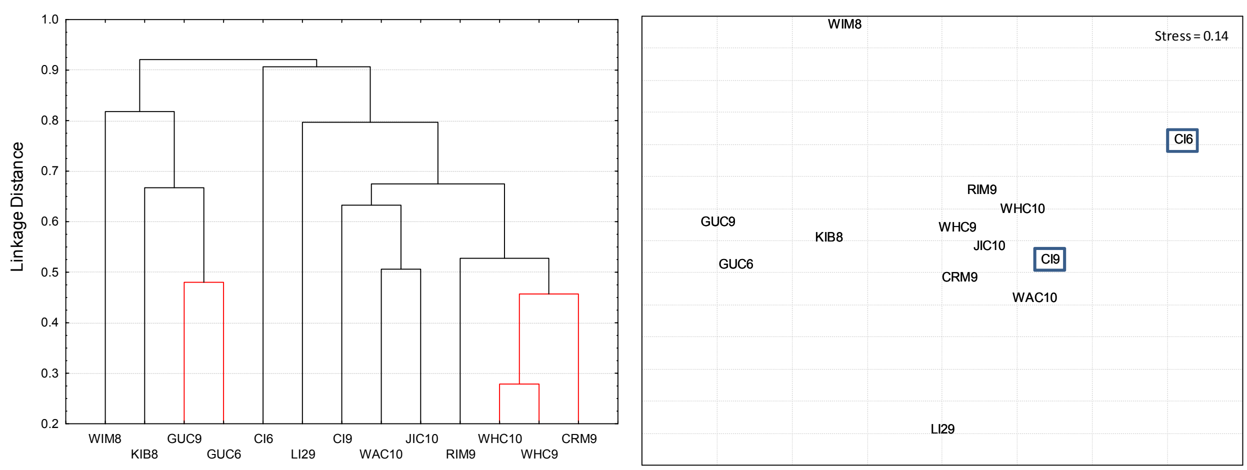


Figure 3.22. Dendrogram (left) and an nMDS plot (right) of the similarity between the restoration site Crims Island relative to mainstem emergent marsh reference sites in hydro-vegetation zone 2 using complete linkage and relative Sørensen's similarity. Red lines on the dendrogram represent a similarity greater than 50%. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006).

Table 3.17. Similarity of the herbaceous strata between the restoration site Hogan Ranch and mainstem emergent marsh reference sites in hydro-vegetation zone 4. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006). Restoration sites are highlighted in yellow and multiple years for a reference site are highlighted in orange. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CLM5	CLM6	CLM7	CLM8	CLM9	CLM10	CS1 5	CS1 6	CS1 7	CS1 8	CS1 9	CS1 10	DMI7	SBM10	SSC5	WRC6	HR4	HR5	HR8	HR10
CLM5	1.00	0.84	0.77	0.77	0.82	0.72	0.79	0.85	0.66	0.77	0.88	0.89	0.49	0.68	0.78	0.36	0.32	0.48	0.77	0.51
CLM6	0.84	1.00	0.71	0.68	0.80	0.63	0.68	0.73	0.66	0.68	0.84	0.81	0.54	0.58	0.66	0.33	0.34	0.38	0.65	0.42
CLM7	0.77	0.71	1.00	0.83	0.82	0.73	0.76	0.77	0.71	0.83	0.74	0.78	0.51	0.61	0.71	0.43	0.44	0.58	0.70	0.49
CLM8	0.77	0.68	0.83	1.00	0.79	0.79	0.84	0.81	0.68	0.89	0.74	0.78	0.52	0.69	0.78	0.34	0.34	0.55	0.79	0.57
CLM9	0.82	0.80	0.82	0.79	1.00	0.71	0.74	0.74	0.70	0.78	0.84	0.83	0.58	0.58	0.68	0.37	0.39	0.50	0.68	0.47
CLM10	0.72	0.63	0.73	0.79	0.71	1.00	0.92	0.79	0.62	0.80	0.67	0.74	0.45	0.77	0.81	0.31	0.33	0.54	0.86	0.65
CS1 5	0.79	0.68	0.76	0.84	0.74	0.92	1.00	0.84	0.65	0.85	0.73	0.79	0.48	0.76	0.86	0.33	0.33	0.54	0.86	0.62
CS1 6	0.85	0.73	0.77	0.81	0.74	0.79	0.84	1.00	0.66	0.84	0.80	0.81	0.47	0.80	0.80	0.41	0.31	0.52	0.90	0.58
CS1 7	0.66	0.66	0.71	0.68	0.70	0.62	0.65	0.66	1.00	0.72	0.68	0.69	0.50	0.50	0.62	0.34	0.36	0.40	0.61	0.40
CS1 8	0.77	0.68	0.83	0.89	0.78	0.80	0.85	0.84	0.72	1.00	0.75	0.81	0.52	0.69	0.81	0.35	0.37	0.57	0.80	0.60
CS1 9	0.88	0.84	0.74	0.74	0.84	0.67	0.73	0.80	0.68	0.75	1.00	0.91	0.52	0.63	0.68	0.37	0.33	0.43	0.74	0.46
CS1 10	0.89	0.81	0.78	0.78	0.83	0.74	0.79	0.81	0.69	0.81	0.91	1.00	0.51	0.64	0.75	0.32	0.34	0.50	0.74	0.52
DMI7	0.49	0.54	0.51	0.52	0.58	0.45	0.48	0.47	0.50	0.52	0.52	0.51	1.00	0.32	0.46	0.24	0.26	0.27	0.42	0.22
SBM10	0.68	0.58	0.61	0.69	0.58	0.77	0.76	0.80	0.50	0.69	0.63	0.64	0.32	1.00	0.72	0.42	0.32	0.53	0.89	0.72
SSC5	0.78	0.66	0.71	0.78	0.68	0.81	0.86	0.80	0.62	0.81	0.68	0.75	0.46	0.72	1.00	0.29	0.43	0.53	0.82	0.61
WRC6	0.36	0.33	0.43	0.34	0.37	0.31	0.33	0.41	0.34	0.35	0.37	0.32	0.24	0.42	0.29	1.00	0.40	0.35	0.41	0.29
HR4	0.32	0.34	0.44	0.34	0.39	0.33	0.33	0.31	0.36	0.37	0.33	0.34	0.26	0.32	0.43	0.40	1.00	0.46	0.32	0.31
HR5	0.48	0.38	0.58	0.55	0.50	0.54	0.54	0.52	0.40	0.57	0.43	0.50	0.27	0.53	0.53	0.35	0.46	1.00	0.52	0.48
HR8	0.77	0.65	0.70	0.79	0.68	0.86	0.86	0.90	0.61	0.80	0.74	0.74	0.42	0.89	0.82	0.41	0.32	0.52	1.00	0.67
HR10	0.51	0.42	0.49	0.57	0.47	0.65	0.62	0.58	0.40	0.60	0.46	0.52	0.22	0.72	0.61	0.29	0.31	0.48	0.67	1.00

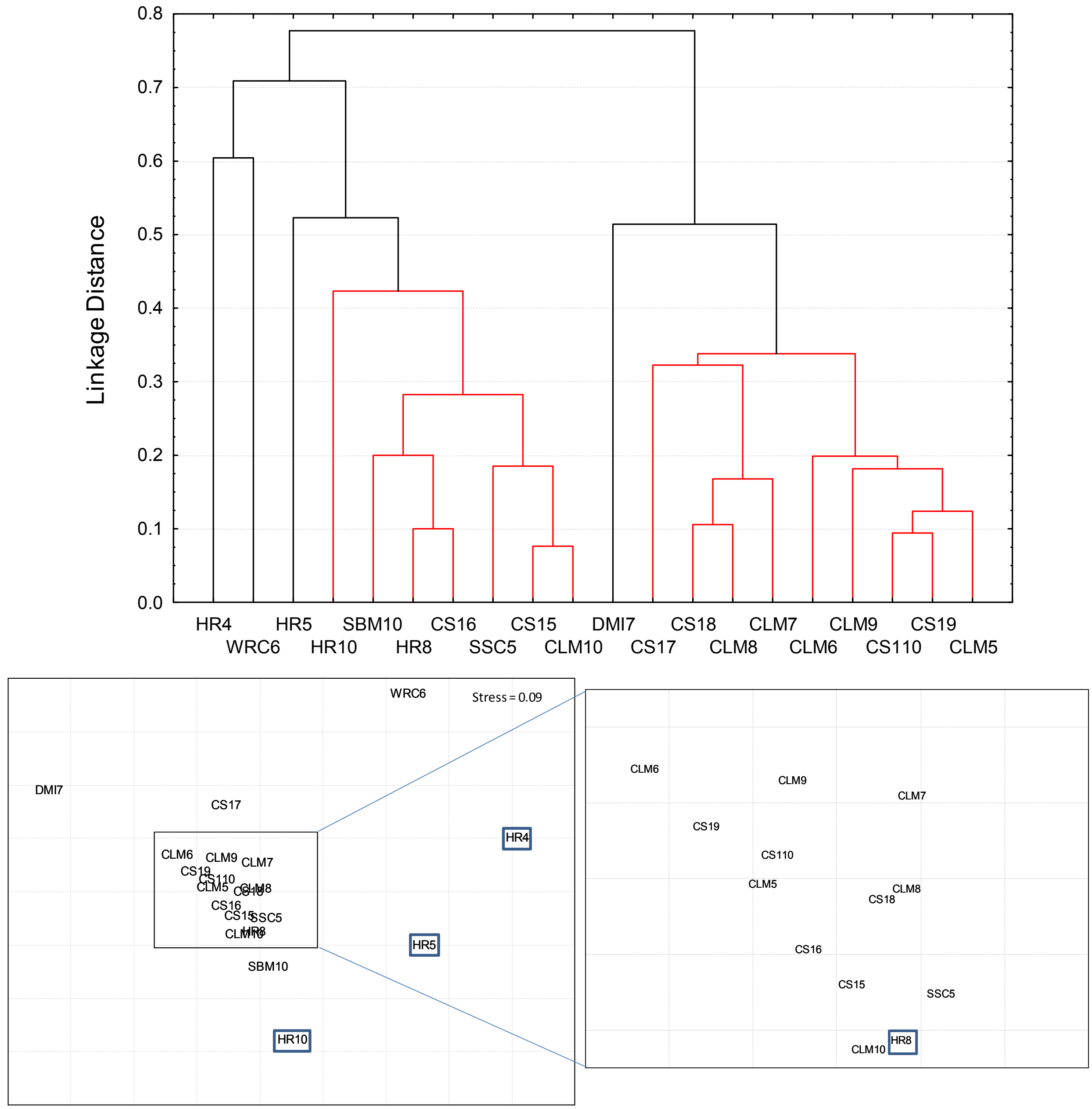


Figure 3.23. Dendrogram (top) and an nMDS plot (bottom) of the similarity between the restoration site Hogan Ranch (blue boxes) relative to selected reference sites using complete linkage and relative Sørensen's similarity. Red lines on the dendrogram represent a similarity greater than 50%. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006).

Table 3.18. Similarity of the shrub strata between the restoration site Mirror Lake and mainstem forested riparian reference sites between rkm 75 and rkm 235. Numbers after the site codes represent the year of sampling (e.g., 6 = 2006). Restoration sites are highlighted in yellow. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CCR09	GCR10	SRR08	ML08	ML09	ML10
CCR09	1.00	0.35	0.61	0.29	0.31	0.31
GCR10	0.35	1.00	0.60	0.26	0.31	0.26
SRR08	0.61	0.60	1.00	0.30	0.34	0.29
ML08	0.29	0.26	0.30	1.00	0.81	0.81
ML09	0.31	0.31	0.34	0.81	1.00	0.81
ML10	0.31	0.26	0.29	0.81	0.81	1.00

Table 3.19. Similarity of the tree strata between the restoration site Mirror Lake and mainstem forested riparian reference sites between rkm 75 and rkm 235. Numbers after the site codes represent the year of sampling (e.g., 6 =2 006). Restoration sites are highlighted in yellow. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CCR09	GCR10	SRR08	ML08	ML09	ML10
CCR09	1.00	0.59	0.70	0.69	0.49	0.46
GCR10	0.59	1.00	0.59	0.75	0.88	0.85
SRR08	0.70	0.59	1.00	0.80	0.55	0.51
ML08	0.69	0.75	0.80	1.00	0.73	0.70
ML09	0.49	0.88	0.55	0.73	1.00	0.95
ML10	0.46	0.85	0.51	0.70		1.00

Table 3.20. Similarity of the shrub strata between the Sandy River Delta restoration site (four subareas) and mainstem forested riparian reference sites between rkm 75 and rkm 235. Numbers after the site codes represent the year of sampling. Restoration sites are highlighted in yellow. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CCR09	GCR10	SRR08	1SRD08	2SRD08	3SRD08	4SRD08	1SRD09	2SRD09	3SRD09	4SRD09	1SRD10	2SRD10	3SRD10	4SRD10
CCR09	1.00	0.35	0.61	0.61	0.32	0.34	0.43	0.52	0.37	0.53	0.55	0.42	0.50	0.37	0.47
GCR10	0.35	1.00	0.60	0.34	0.20	0.23	0.34	0.38	0.26	0.39	0.37	0.29	0.32	0.21	0.33
SRR08	0.61	0.60	1.00	0.57	0.23	0.21	0.39	0.49	0.28	0.43	0.52	0.34	0.42	0.24	0.38
1SRD08	0.61	0.34	0.57	1.00	0.36	0.33	0.47	0.65	0.38	0.53	0.54	0.62	0.48	0.39	0.47
2SRD08	0.32	0.20	0.23	0.36	1.00	0.34	0.43	0.46	0.82	0.34	0.41	0.45	0.62	0.40	0.45
3SRD08	0.34	0.23	0.21	0.33	0.34	1.00	0.26	0.27	0.44	0.46	0.27	0.33	0.49	0.77	0.28
4SRD08	0.43	0.34	0.39	0.47	0.43	0.26	1.00	0.55	0.43	0.44	0.65	0.45	0.42	0.30	0.66
1SRD09	0.52	0.38	0.49	0.65	0.46	0.27	0.55	1.00	0.47	0.47	0.60	0.56	0.50	0.29	0.49
2SRD09	0.37	0.26	0.28	0.38	0.82	0.44	0.43	0.47	1.00	0.40	0.44	0.41	0.67	0.48	0.42
3SRD09	0.53	0.39	0.43	0.53	0.34	0.46	0.44	0.47	0.40	1.00	0.47	0.61	0.48	0.63	0.47
4SRD09	0.55	0.37	0.52	0.54	0.41	0.27	0.65	0.60	0.44	0.47	1.00	0.44	0.53	0.32	0.64
1SRD10	0.42	0.29	0.34	0.62	0.45	0.33	0.45	0.56	0.41	0.61	0.44	1.00	0.48	0.50	0.54
2SRD10	0.50	0.32	0.42	0.48	0.62	0.49	0.42	0.50	0.67	0.48	0.53	0.48	1.00	0.57	0.52
3SRD10	0.37	0.21	0.24	0.39	0.40	0.77	0.30	0.29	0.48	0.63	0.32	0.50	0.57	1.00	0.34
4SRD10	0.47	0.33	0.38	0.47	0.45	0.28	0.66	0.49	0.42	0.47	0.64	0.54	0.52	0.34	1.00

Table 3.21. Similarity of the tree strata between the Sandy River Delta restoration site (four subareas) and mainstem forested riparian reference sites between rkm 75 and rkm 235. Numbers after the site codes represent the year of sampling. Restoration sites are highlighted in yellow. Similarity values greater than 50% are highlighted in light yellow and greater than 75% are highlighted in green.

	CCR09	GCR10	SRR08	1SRD08	2SRD08	3SRD08	4SRD08	1SRD09	2SRD09	3SRD09	4SRD09	1SRD10	2SRD10	3SRD10	4SRD10
CCR09	1.00	0.59	0.70	0.61	0.52	0.51	0.57	0.58	0.43	0.38	0.57	0.53	0.36	0.37	0.51
GCR10	0.59	1.00	0.59	0.90	0.87	0.90	0.90	0.93	0.82	0.76	0.84	0.91	0.75	0.76	0.87
SRR08	0.70	0.59	1.00	0.67	0.60	0.56	0.63	0.64	0.51	0.46	0.64	0.58	0.42	0.44	0.58
1SRD08	0.61	0.90	0.67	1.00	0.88	0.87	0.95	0.95	0.80	0.76	0.89	0.90	0.73	0.75	0.89
2SRD08	0.52	0.87	0.60	0.88	1.00	0.86	0.89	0.88	0.84	0.82	0.85	0.90	0.72	0.74	0.89
3SRD08	0.51	0.90	0.56	0.87	0.86	1.00	0.89	0.92	0.89	0.86	0.84	0.90	0.83	0.84	0.88
4SRD08	0.57	0.90	0.63	0.95	0.89	0.89	1.00	0.93	0.80	0.77	0.94	0.89	0.73	0.75	0.91
1SRD09	0.58	0.93	0.64	0.95	0.88	0.92	0.93	1.00	0.85	0.80	0.88	0.93	0.78	0.79	0.88
2SRD09	0.43	0.82	0.51	0.80	0.84	0.89	0.80	0.85	1.00	0.95	0.76	0.83	0.89	0.91	0.81
3SRD09	0.38	0.76	0.46	0.76	0.82	0.86	0.77	0.80	0.95	1.00	0.72	0.78	0.89	0.92	0.78
4SRD09	0.57	0.84	0.64	0.89	0.85	0.84	0.94	0.88	0.76	0.72	1.00	0.84	0.67	0.70	0.87
1SRD10	0.53	0.91	0.58	0.90	0.90	0.90	0.89	0.93	0.83	0.78	0.84	1.00	0.77	0.78	0.91
2SRD10	0.36	0.75	0.42	0.73	0.72	0.83	0.73	0.78	0.89	0.89	0.67	0.77	1.00	0.91	0.74
3SRD10	0.37	0.76	0.44	0.75	0.74	0.84	0.75	0.79	0.91	0.92	0.70	0.78	0.91	1.00	0.77
4SRD10	0.51	0.87	0.58	0.89	0.89	0.88	0.91	0.88	0.81	0.78	0.87	0.91	0.74	0.77	1.00

3.2.6 Tidal Channels

Tidal channels are a critical component of wetlands in the LCRE and are important in the conveyance of water to and from the sites. The morphology of these features is one aspect of a restoration site that can be measured against reference systems. One method for comparison is to evaluate the relationship between channel length and channel area at the outlet. In general, a longer channel results in a greater area at the outlet (Figure 3.24). When this relationship does not hold true, then some factor must be affecting the relationship. For example, a marsh that has subsided during diking would result in a greater quantity of water moving in and out of the system and could, in turn, result in a deeper channel outlet relative to channel length (Diefenderfer et al. 2008). This factor could explain the greater channel areas measured at the Kandoll Farm restoration site and two of the historically breached sites (Figure 3.24). In contrast, the Fort Clatsop restoration site has a smaller than expected outlet area, which could possibly be explained by a constriction at the channel mouth.

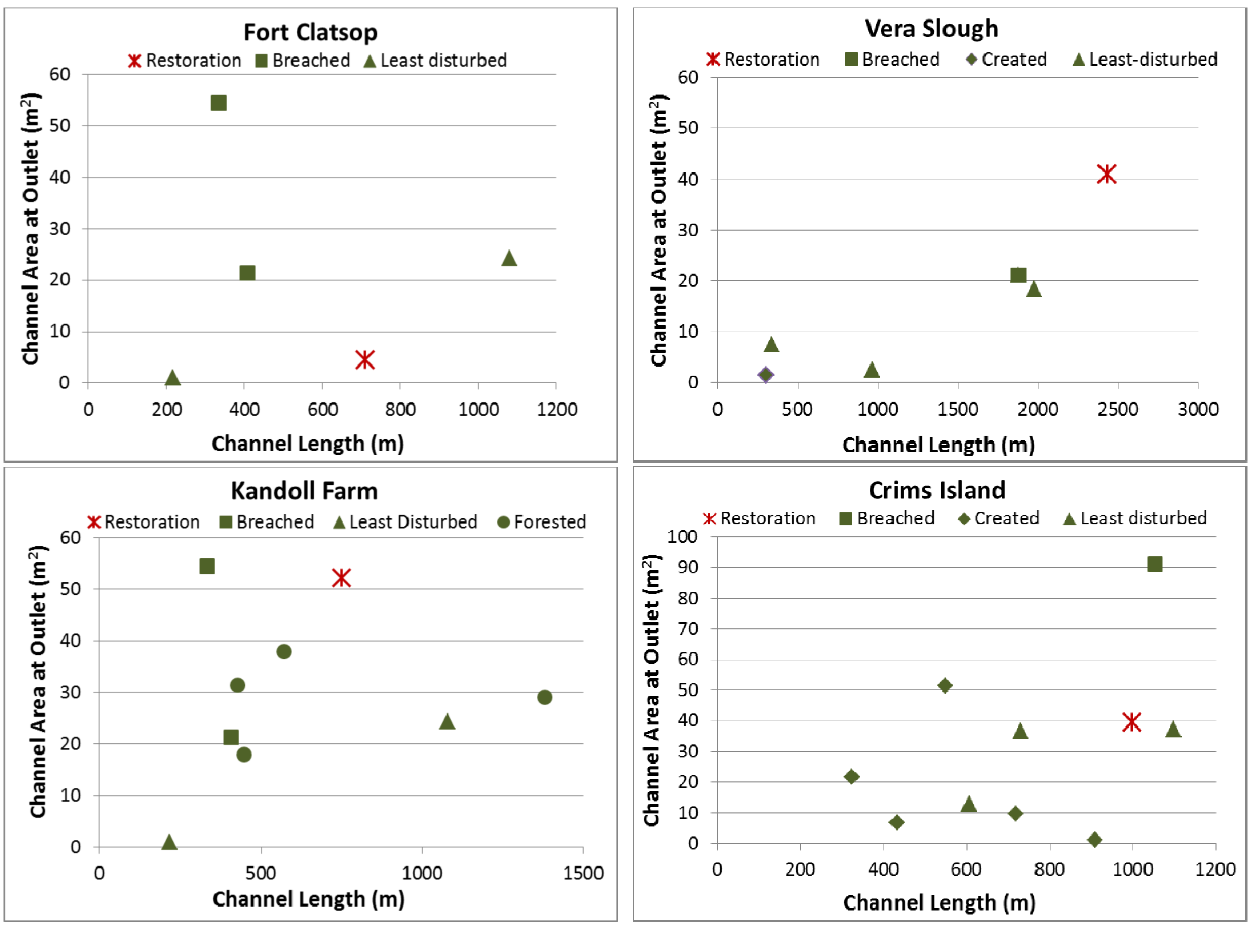


Figure 3.24. Relationship between channel length and channel cross sectional area at the outlet for restoration (red points) and associated reference sites (green points). Note that the *x*-axes are variable on the plots.

Another morphological metric is the relationship between channel width and depth at the outlet. Fort Clatsop and Kandoll Farm have the expected channel morphometry based on the reference sites, while Vera Slough and Crims Island are deeper than what would be expected for their width (Figure 3.25). The depth at Vera Slough immediately inside and outside the tide gate increased post-restoration, which may be explained by scouring due to the increased flows through the tide gates. At Crims Island, the channel was presumably excavated to the observed depth.

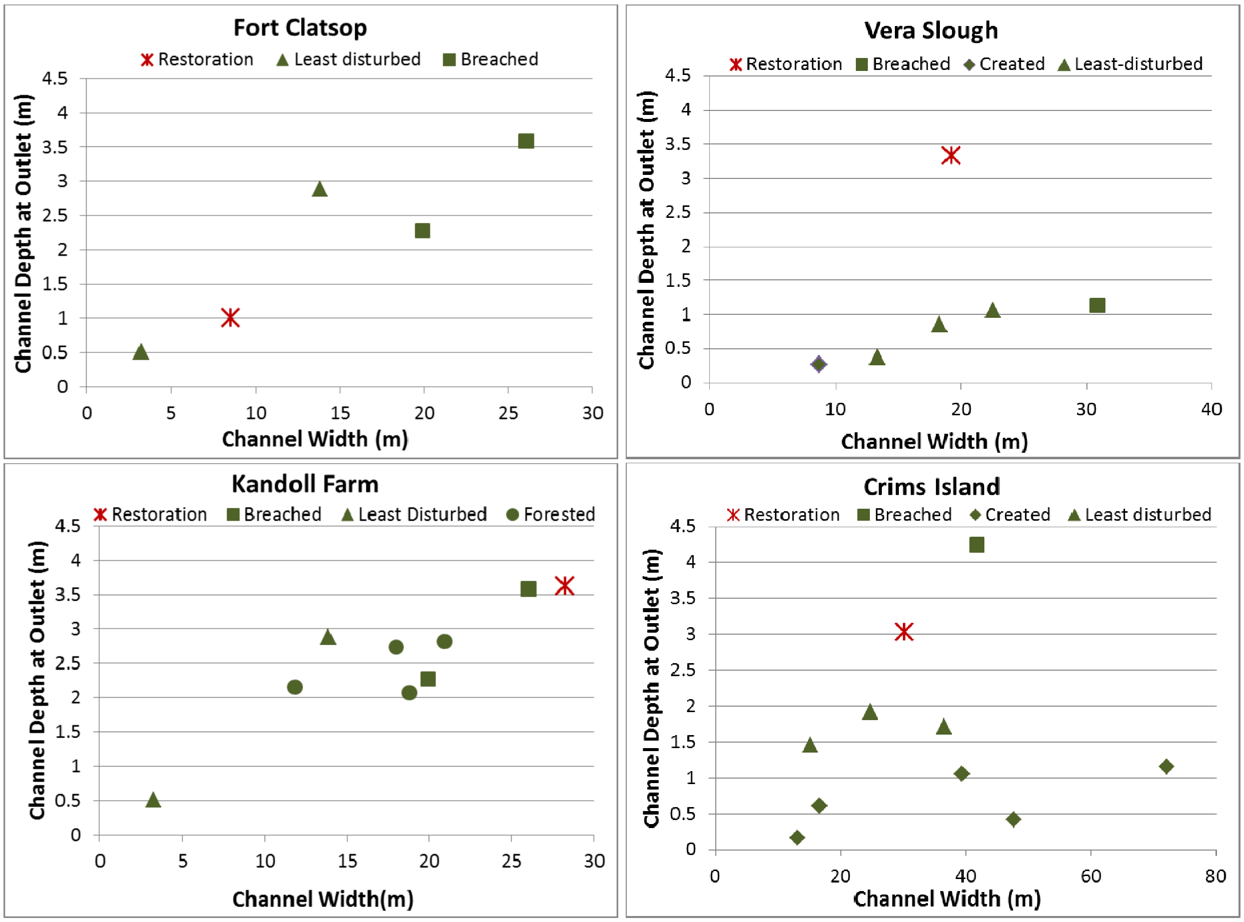


Figure 3.25. Relationship between channel width and channel depth at the outlet for restoration and associated reference sites. Note that the *x*-axes are variable on the plots.

4.0 Conclusions and Recommendations

4.1 Conclusions

We summarize the conclusions from the Reference Site study according to two main topics: 1) gradients in the vegetation assemblages relative to hydrodynamics and other factors; and 2) the relative similarity of restored sites to reference sites. Our conclusions are provided in the following subsections.

4.1.1 Vegetation Assemblage Gradients

Shallow-water vegetation assemblages show distinct differences along the gradient between the mouth of the river and the upstream end of the estuary at Bonneville Lock and Dam. There are three zones based on species richness; the central region (rkm 50 to rkm 150) has the greatest number of species, and the upper and lower ends of the estuary have lower numbers of species. These three species richness zones can be characterized hydrodynamically as tidal-dominated, mixed tidal and river-dominated, and river-dominated, moving from the mouth of the Columbia River to Bonneville Dam.

We hypothesize that fewer vegetation species are physiologically adapted to the extreme inundation in the upper end of the estuary, and, likewise, few are adapted to the tidal variability and salinity in the lower estuary. The fact that the mixed zone contains the greatest number of species suggests that the natural ecological disturbance regime may be lower there, and there may be a larger species pool adapted for these conditions in this zone. This intermediate disturbance hypothesis has been used in many ecosystems to describe the conditions that result in higher species diversity (e.g., Levin and Paine 1974, Connell 1978, Bertness and Ellison 1987).

Further examination of the hydrologic gradient revealed that the estuary can be divided further into five zones, driven primarily by salinity intrusion at the lower end, and stronger fluvial flooding influence at the upper end. The breaks for these zones occur at approximately rkm 40, 104, 136, and 181. These breaks are preliminary and should be refined with additional data in areas of sparse sites and with other hydrologic analyses currently underway (Jay et al. in revision).

The five hydro-vegetation zones developed from this analysis provide a means of determining the ranges of controlling factors (e.g., elevation, hydrology, accretion rates) at reference sites within each zone. These ranges can then be used to inform restoration planning for sites within each zone. Further, the zones provide a means of comparing restoration sites to relevant reference sites that have similar factors controlling their habitat structure, as discussed below.

The elevation range for the major habitat types (e.g., emergent, shrub, or forested wetland) within a zone is small (i.e., < 2m), which strongly suggests that elevation/hydrodynamics must be carefully considered 1) in the design of wetland restoration sites, 2) the analysis of differences between sites, and 3) the trajectories and rate of development of restored sites.

With the results from this analysis, the elevation and possibly the growing season SEV can be used to predict species presence at sites within the same hydro-vegetation zone. For example, the invasive species reed canary-grass (*Phalaris arundinacea*) covered the widest range in elevation of any species. In general, these data on elevations of vegetation species should help in planning restoration actions to maximize native species and minimize the invasion of reed canary-grass into new sites.

4.1.2 Relative Similarity of Restored to Reference Sites

In this section, we summarize the findings from the restoration and reference site comparison then also provide a judgment of the usefulness of the metric and the analysis as a restoration performance measure.

Sediment Accretion. Most restored sites showed initiation of the process of sedimentation. Accretion indicates that the sites are behaving as sinks of sediment and probably organic matter—two processes indicative of wetland systems. Accretion rates tended to be greater in restored sites as compared to the least-disturbed reference sites.

> *Usefulness of metric*: Sediment accretion is required to build wetland elevations and is easily and cost-effectively measured in the field. This metric provided a valuable means of comparing restoration to reference conditions in the analysis.

Elevation. Elevations of previously diked restored sites were lower than reference sites. Again, this suggests that accretion is needed to restore the sites to the historical vegetation assemblage. The excavated site was more similar to reference elevations than the other hydrologically reconnected sites.

> *Usefulness of metric*: This metric can be difficult and expensive to measure in the field, but is invaluable to determine the likelihood of a site establishing the target hydrologic patterns and vegetation community. The simple comparison of the average, minimum, and maximum elevations proved a simple means of comparing the site elevations.

Inundation. Natural hydrological connection and dynamics were restored at the two sites where sufficient hydrological data were available. The hydrologic patterns are likely driving the development and function of the restored sites.

> *Usefulness of metric*: Hydrologic data are essential to determining whether a site has the necessary processes for wetland development. The lack of data from restoration sites resulted in few comparisons, however, we feel the analysis of SEV could be a useful means of evaluating the effect of hydrologic patterns on vegetation particularly when the elevation or hydrology are expected to be different from reference conditions.

Water Temperature. Water temperature in restored and reference sites typically first exceeded the WADOE threshold value for juvenile salmon in late spring. In a few cases, the temperature exceedance occurred later in reference sites than at the restoration sites, likely due to proximity to the main channel and local effects of shade. At the few restoration sites where we had data from multiple sensors within a site, patterns were evident relative to the distance from the outlet or the presence/absence of perennial stream inputs. We did not have pre-restoration data on temperatures but, based on data from a few sites collected before reconnection, we believe that water temperature after reconnection probably remained below the threshold longer as compared to pre-reconnection at the sites we studied.

Usefulness of metric: Temperature is a useful metric for evaluating conditions within wetland areas, particularly habitat function for aquatic species. The date of first exceedance of a temperature criterion is a viable method for determining differences between sites and also for evaluating the condition of the habitat provided at a site.

Vegetation Composition. The bivariate analysis showed that the composition of selected species at some restoration sites was tending toward the composition at the reference sites. The probability of occurrence showed that the species composition of the highest-cover species at the restoration sites was not the same as that of the reference sites, although some similar species were present and increasing over time. Invasive species, particularly reed canary-grass, were a problem at all restoration sites.

Usefulness of metric: The bivariate analysis is a useful way to compare the cover and composition of desired species. The analysis is most useful when reed canary-grass is not highly dominant in the reference sites that are used to compare to the restoration site. This species was not included in the bivariate analysis because it is not one that is "desirable" in these systems. However, the species is very dominant and affects the cover of many other species that occur within the same elevation range at both restoration and some reference sites.

The probability of occurrence analysis was a useful way to look at the most common species at the sites and compare the cover and composition over time and between the restoration and reference sites.

Vegetation Similarity. The vegetation assemblages at nearly all restoration sites had very low similarity to reference site vegetation. Hogan Ranch and the sites planted with shrubs and trees showed the highest similarity. Sites that were historically forested swamps, and had been converted to pasture land, showed the lowest similarities to their reference sites. Where data were available for multiple years, restoration sites showed a decreasing similarity from the earliest sampling to the most recent. This suggests that the vegetation is changing rapidly from the initial conditions. Based on previous studies (e.g., Thom et al. 2002), we suspect that similarity between restored sites and their reference sites will increase measurably over time but not for at least another 5–10 years.

This analysis showed there to also be variability between the reference sites, which could be caused by factors such as recent and historical disturbances (e.g., dredged material placement). This variability illustrates the need to evaluate reference site differences and possibly further stratify the reference sites for comparison to restoration sites.

The reference site similarity was also variable between years. Thom et el. (2002) found similar results and suggests using the long-term average similarity in reference sites to establish a target similarity between the restoration site and reference site. Because most sites were measured in one year only, and not always in the same year for all reference sites in the zone, this temporal variability must be included in determining the target similarity for the restoration sites.

Usefulness of metric: The similarity index is a very useful way to make broad comparisons based on the vegetation cover and composition between sites and over time.

Channel Morphometry. The channel length plotted against channel cross sectional area at the mouth was an effective means of comparing the restoration and reference sites. Of the four restoration sites compared, one appeared to have too small of a channel outlet, one was unnecessarily large, and two were within the same range or at the expected ratio found at the reference sites. We suspect that the restored channels will trend toward reference site dimensions if hydrological connection is unconstrained.

Channel width at the outlet plotted against the channel depth at the outlet confirmed that two of the channels had similar dimensions to the reference channels and two were considerably deeper relative to the width as compared to the reference channels. Interestingly, these two sites were also the ones with the most similar length-to-area ratios, so perhaps the deeper channels are necessary to adequately drain the area at these sites.

> *Usefulness of metric*: Analysis of channel morphometry can be used to determine the similarity of restoration channels to reference channels when other metrics of hydraulic geometry are not available (e.g., catchment area and total channel length; see Diefenderfer et al. 2008). We found that the primary channel length versus cross-sectional area at the mouth may be a useful measure. However, because channels in reference systems are often complex this analysis should be compared to reference sites using the complete channel network to determine if the relationship is valid. The width-to-depth ratio of channel outlet is useful to evaluate whether a restoration channel is similar to reference channels; however, it does not reflect whether these dimensions are appropriate relative to the size of the site.

Overall, our findings provide new information on factors structuring shallow water vegetated habitats along the entire estuary gradient. The relationships between location, hydrology, and elevation provide valuable potential predictors useful in restoration planning, and to evaluate the rates and trajectories of restored sites.

4.2 Recommendations

The following recommendations resulting from this study and are specific to the methods for future analysis. These are not recommendations for restoration actions.

4.2.1 Data Management

Specific recommendations for data management include the following:

- Data organization and summarizing needs to be standardized across data collection efforts.
- Develop continuous datasets for all time-series metrics.
- Use USDA plant database for vegetation identification (or identify which field guide used).
- Record vegetation data using scientific name, rather than common name
- Measure elevation data in NAVD88 via local benchmark then convert to the Columbia River Datum where appropriate (i.e., above rkm 35 in the mainstem; not in tributary sites).
- Compile summarized data into one database/spreadsheet for analysis.

4.2.2 Reference to Restoration Site Comparisons

The following recommendations would improve the ability to make comparisons between reference sites and restoration sites in the future:

- The differences between reference sites because of recent and historical disturbances need to be evaluated and possibly stratified further prior to comparison to restoration sites.
- Interannual variability needs to be better quantified at reference sites within the estuary.
- Channels in reference systems are often complex. The analysis conducted here on primary channel length should be compared to one using the complete channel network to determine if the relationship between primary channel length and area at channel outlet is valid.
- Additional monitoring data are needed at restoration sites to better understand if sites are developing toward fully functioning and resilient ecosystems, to inform the adaptive management process, and ultimately improve restoration action effectiveness in the future.

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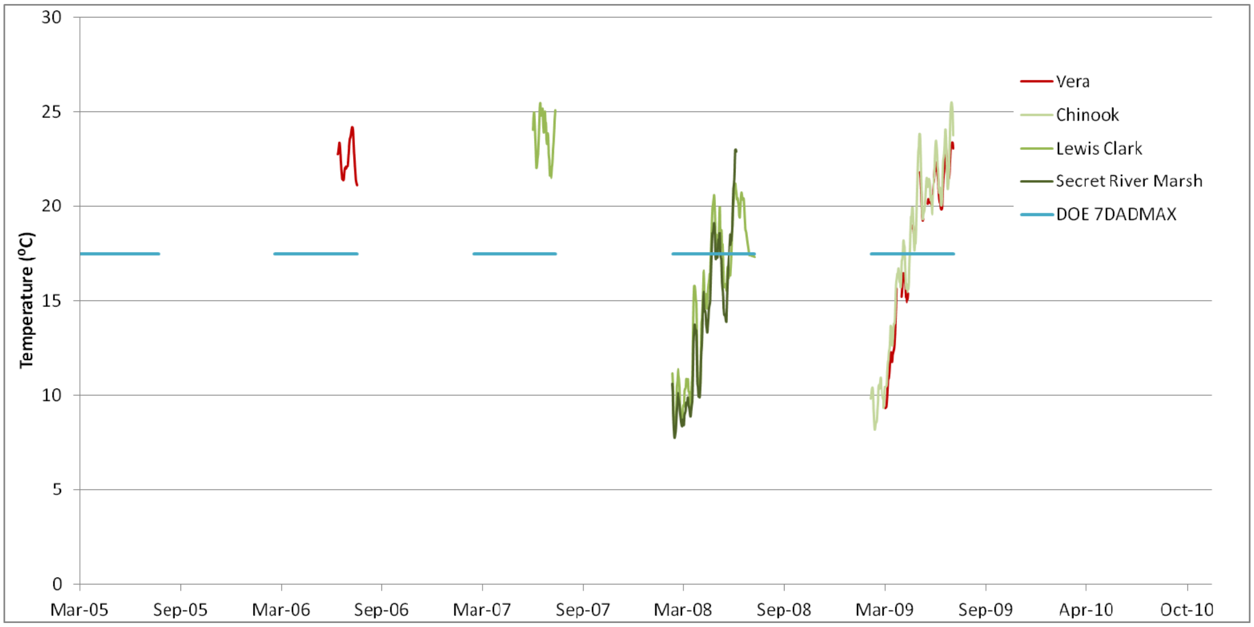
Appendix A

Temperature Graphs

Appendix A

Temperature Graphs



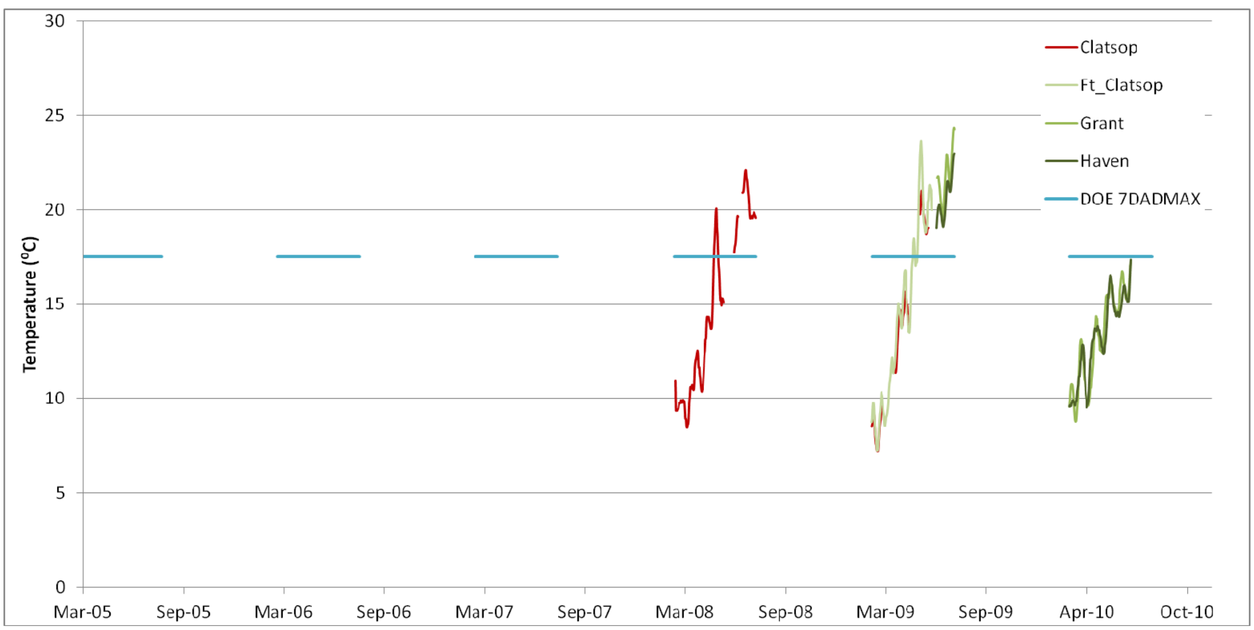
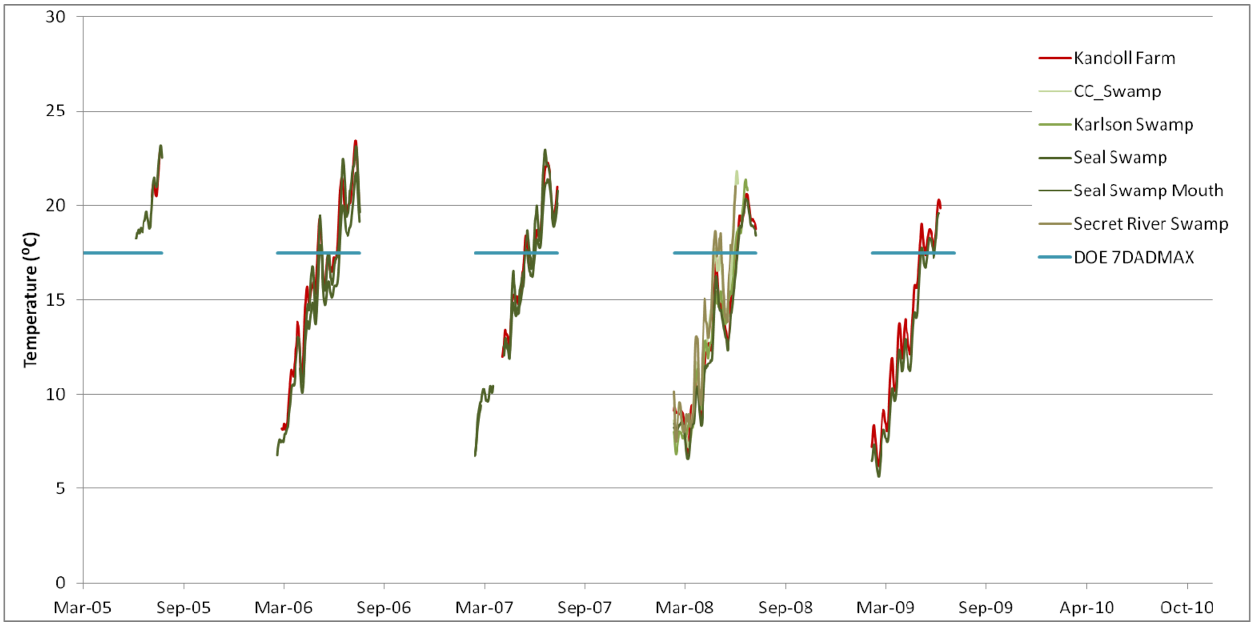


Figure A.1. The seven-day running average of the daily maximum (7DADmax) between March and July for restoration and reference sites in same hydro-vegetation zone and geomorphic setting (tributary vs. main channel). Restoration sites are shown in red and restoration sites in shades of green.



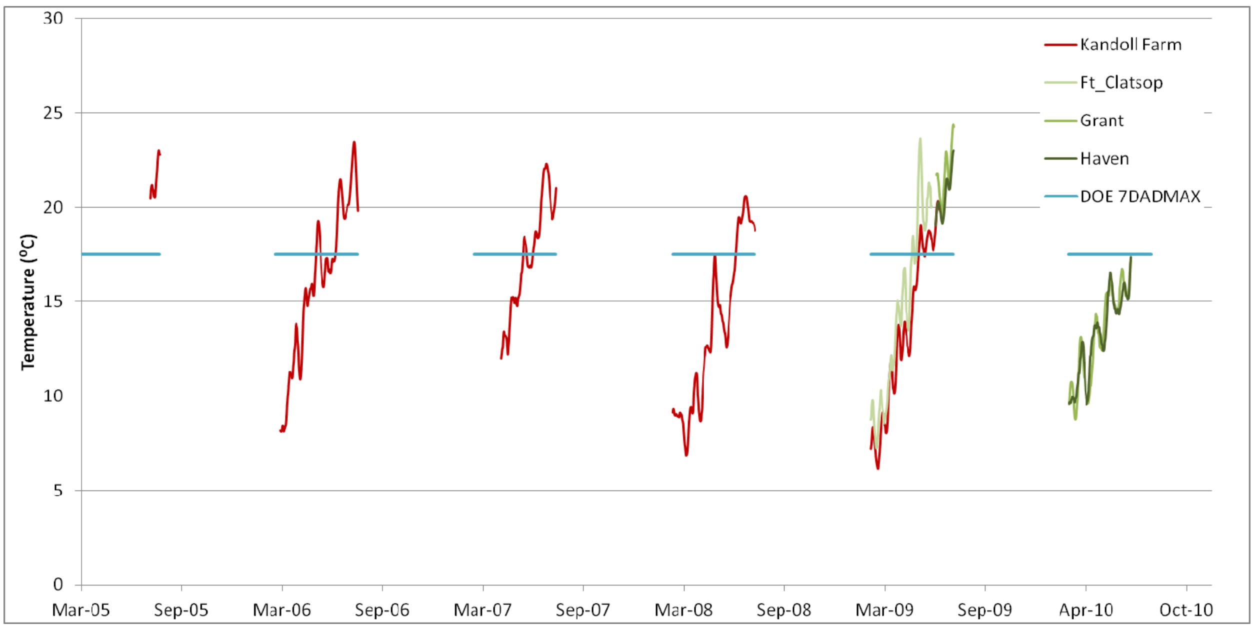
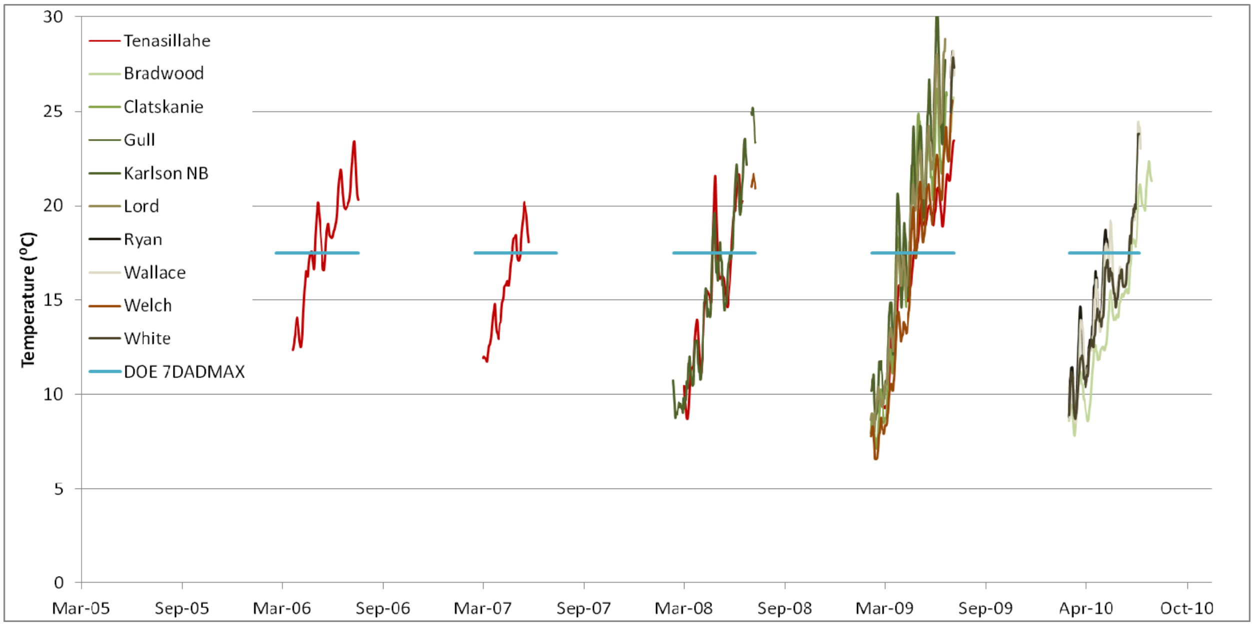


Figure A.1. (contd)



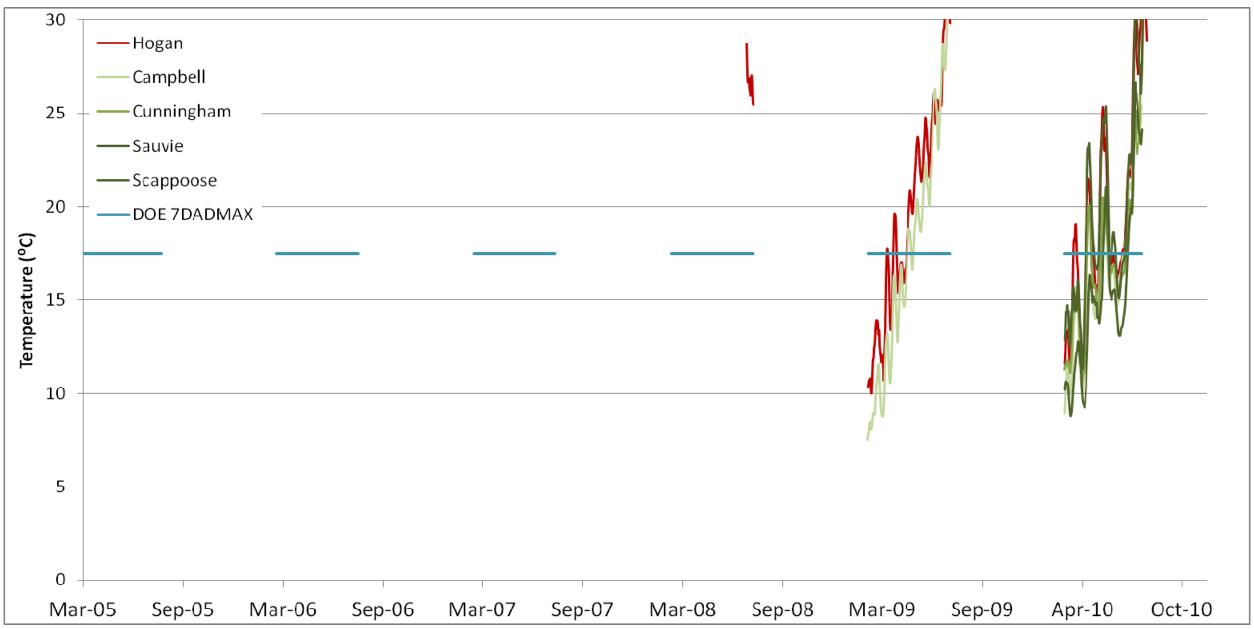
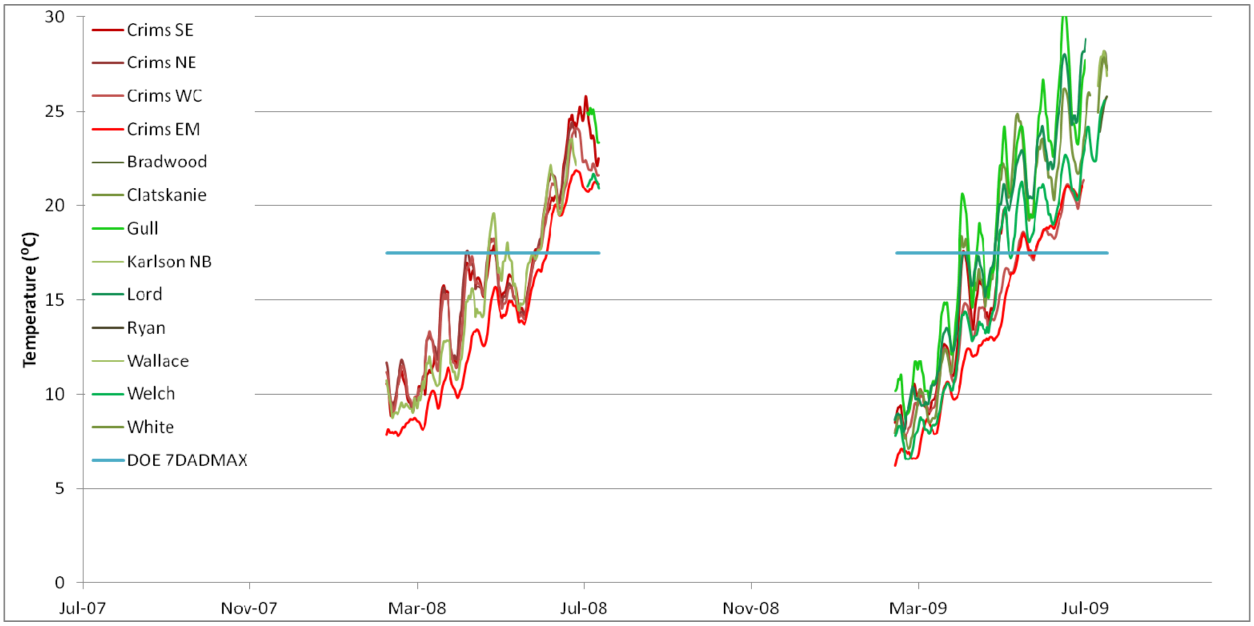
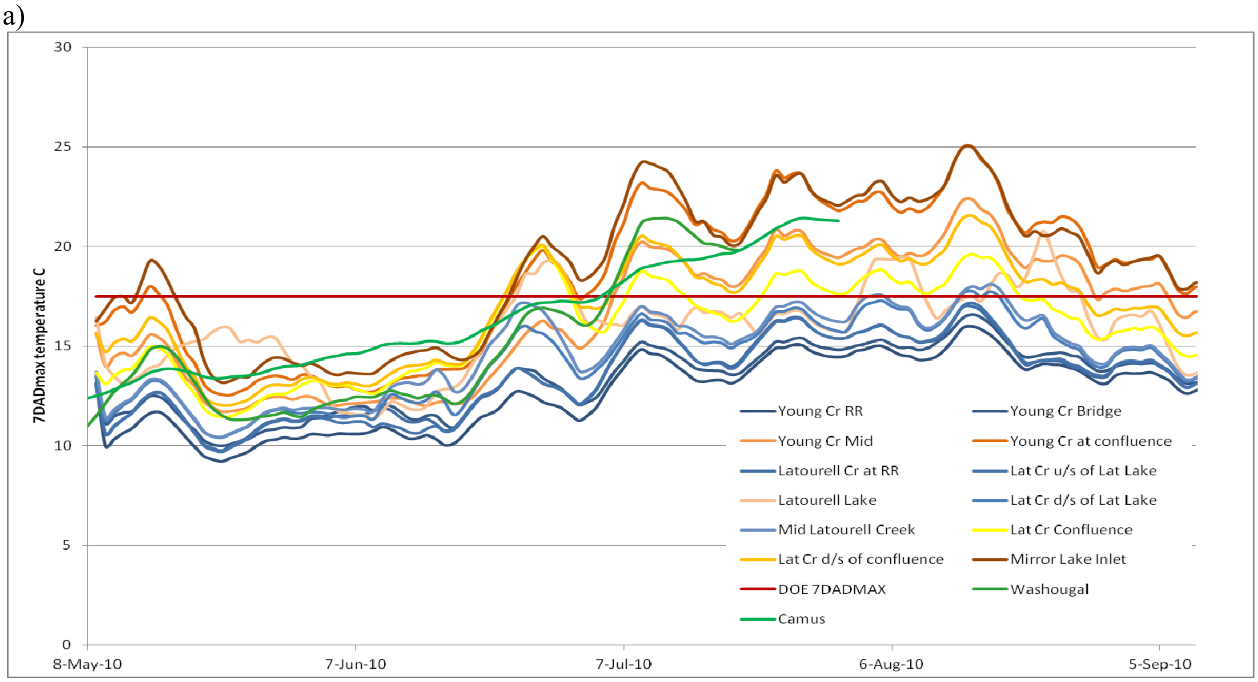


Figure A.1. (contd)



a)



b)

Figure A.2. Temperature from multiple sensors at a) Crims Island and b) Mirror Lake compared to nine and one reference site(s), respectively. The Mirror Lake data is also compared to temperature data from Camas on the mainstem.

Appendix B

LCR Reference and Restoration Site Study Plant List

Appendix B

LCR Reference and Restoration Site Study Plant List

Table B.1 lists all plant species observed at all reference sites monitored by PNNL from 2005-2010. Table B.2 lists species observed by others during restoration monitoring that were not already included in the PNNL species list. Note that the "Invasive/Weedy" column has not been comprehensively addressed. Species immediately known to be invasive have been noted with a "yes" in the column; however, other species could warrant the same categorization but adequate research has not been conducted in this study to date.

Table B.1. Plant species observed at all reference sites monitored by PNNL from 2005 through 2010.

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Species observed at reference sites								
Acer circinatum	ACCI	Vine maple	FAC-	Shrub	yes			
Adiantum aleuticum	ADAL	Aleutian Maidenhair fern	FAC	Fern	yes		formerly *Adiantum pedatum*	ADPE
Agrostis capillaris	AGCA	Colonial bentgrass	FAC	Grass	no			
Agrostis exarata	AGEX	spike bentgrass	FACW	Grass	yes			
Agrostis gigantea	AGGI	redtop; black bentgrass	NI	Grass	no			
Agrostis oregonensis	AGOR	Oregon bentgrass	FAC	Grass	yes			
Agrostis stolonifera L.	AGST	creeping bentgrass	FAC	Grass	no	yes		
Alisma triviale	ALTR	northern water plaintain	OBL	Herb	yes		formerly *Alisma plantago-aquatica* var. americanum	ALPL
Alnus rubra	ALRU	Red alder	FAC	Tree	yes			
Alopecurus pratensis	ALPR	Meadow foxtail	FACW	Grass	no			
Amelanchier alnifolia	AMAL	Saskatoon serviceberry	FACU	Shrub	yes			
Amorpha fruticosa	AMFR	indigo bush	FACW	Shrub	no	yes		
Angelica arguta	ANAR	Sharptooth angelica	FACW	Herb	yes			
Angelica genuflexa	ANGE	Kneeling angelica	FACW	Herb	yes			
Apocynum cannabinum	APCA	dogbane, Indian hemp	FAC+	Herb	yes			
Aruncus dioicus	ARDI	Goat's beard	FACU+	Herb	yes			
Asplenium trichomanes-ramosum	ASTR	Green spleenwort	FACU	Herb	yes		formerly *Asplenium viride*	ASVI
Athyrium filix-femina	ATFI	Lady fern	FAC	Fern	yes			
Atriplex patula	ATPA	spear saltbush	FACW	Herb	yes			
Beckmannia syzigachne	BESY	American sloughgrass	OBL	Grass	yes			
Bidens cernua	BICE	Nodding beggars-ticks	FACW+	Herb	yes	yes		
Bidens frondosa	BIFR	devil's beggartick	FACW+	Herb	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Blechnum spicant	BLSP	Deer fern	FAC+	Fern	yes			
Calamagrostis canadensis	CACA	bluejoint	FACW+	Grass	yes			
Calamagrostis spp.	CASP2	reedgrass		Grass	yes			
Callitriche heterophylla	CAHE	Twoheaded water starwort	OBL	Herb	yes			
Caltha palustris	CAPA	Yellow marsh marigold	OBL	Herb	yes			
Calystegia sepium	CASE	Hedge bindweed	FAC	Herb	no		formerly *Convolvulus sepium*	COSE; COSE1
Cardamine angulata	CAAN	Angled bittercress	FACW	Herb	yes			
Cardamine pensylvanica	CAPE	Pennsylvania bittercress	FACW	Herb	no			
Carex aperta	CAAP	Columbia sedge	FACW	Sedge	yes		nearly exterpated in CR	
Carex athrostachya	CAAT	slender-beak sedge	FACW	Sedge	yes			
Carex comosa	CACO	Bearded sedge	OBL	Sedge	yes		sensitive spp in WA	
Carex densa	CADE2	dense dedge	OBL	Sedge	yes		threatened	
Carex deweyana	CADE	Dewey sedge	FAC+	Sedge	yes			
Carex disperma	CADI	Soft-leaved sedge	FACW	Sedge	yes			
Carex echinata	CAEC	star sedge	NI	Sedge	yes			
Carex lyngbyei	CALY	Lyngby sedge	OBL	Sedge	yes			
Carex obnupta	CAOB	Slough sedge	OBL	Sedge	yes			
Carex sp.	CASP	Carex	mixed	Sedge	yes			
Carex stipata	CAST	Sawbeak sedge	FACW	Sedge	yes			
Carex vesicaria	CAVE	inflated sedge, blister sedge	OBL	Sedge	yes			
Castilleja ambigua	CAAM	paint-brush owl-clover; johnny-nip	FACW+	Herb	yes			ORCA
Ceratophyllum demersum	CEDE	Coontail	OBL	Herb	yes		SAV	
Chamerion angustifolium	CHAN	Fireweed	FACU+	Herb	yes		formerly *Epilobium angustifolium*	EPAN

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Chenopodium album	CHAL	lambsquarters	FAC	Herb	no	yes	possibly var. striatum, which is native	
Cicuta douglasii	CIDO	Western water-hemlock	OBL	Herb	yes	yes		
Cirsium arvense var. horridum	CIAR	Canada thistle	FACU+	Herb	no	yes		
Cirsium vulgare	CIVU	bull thistle	FACU	Herb	no	yes		
Claytonia sibirica	CLSI	Candy flower; Siberian spring beauty	FAC	Herb	yes			
Comarum palustre	COPA	purple marshlocks, marsh cinquefoil	OBL	Herb	yes		formerly *Potentilla palustris*	POPA
Conium maculatum	COMA	Poison hemlock	FAC+	Herb	no			
Convolvulus arvensis	COAR	Morning glory; Field bindweed	UPL	Herb	no	yes		
Coreopsis tinctoria	COTI	golden tickseed	FACU	Herb	yes			
Cornus canadensis	COCA	bunchberry	FAC	Shrub	yes			
Cornus sericea	COSE	Red-osier dogwood	FACW	Shrub	yes			COST
Corylus cornuta	COCO2	beaked hazelnut	FACU	Tree	yes			
Cotula coronopifolia	COCO	common brassbuttons	FACW+	Herb	no			
Crataegus douglasii	CRDO	black hawthorn	FAC	Shrub	yes			
Cyperus sp.	CYSP	flatsedge		Herb	mixed			
Cyperus strigosus	CYST	Strawcolor flatsedge; nutsedge	FACW	Sedge	yes			
Dactylis glomerata	DAGL	Orchard-grass	FACU	Grass	no			
Deschampsia cespitosa	DECE	Tufted hairgrass	FACW	Grass	yes			
Digitaria ischaemum	DIIS	smooth crabgrass	FACU	Grass	no			
Digitaria sanguinalis	DISA	hairy crabgrass	FACU	Grass	yes			
Digitaria sp.	DISP	crabgrass	FACU	Grass	mixed			
Distichlis spicata	DISP2	saltgrass	FACW	Grass	yes			
Eleocharis acicularis	ELAC	Needle spikerush	OBL	Sedge	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Eleocharis ovata	ELOV	Ovoid spikerush	OBL	Sedge	yes			
Eleocharis palustris	ELPA	Common spikerush	OBL	Sedge	yes			
Eleocharis parvula	ELPAR	Dwarf spikerush	OBL	Sedge	yes			
Eleocharis spp.	ELSP	Spikerush	OBL	Sedge	yes			
Elodea canadensis	ELCA	Canada waterweed	OBL	Herb	yes		SAV	
Elodea nuttallii	ELNU	Nuttall's waterweed, western waterweed	OBL	Herb	yes		SAV	
Elymus repens	ELRE	Quackgrass	FAC-	Grass	no	yes		
Epilobium ciliatum	EPCI	Willow herb	FACW-	Herb	yes			
Equisetum fluviatile	EQFL	Water horsetail	OBL	Fern	yes			
Equisetum hyemale	EQHY	scouringrush horsetail	FACW	Fern	yes		Lord Is 1	
Equisetum palustre	EQPA	marsh horsetail	FACW	Fern	yes			
Equisetum spp.	EQSP	Horsetail	mixed	Fern	yes			
Equisetum telmateia	EQTE	giant horsetail	FACW	Fern	yes			
Euthamia occidentalis	EUOC	western goldentop	FACW*	Herb	yes			
Frangula purshiana	FRPU	Cascara	FAC-	Tree	yes		formerly Rhamnus purshiana	RHPU
Fraxinus latifolia	FRLA	Oregon ash	FACW	Tree	yes			
Fucus distichus	FUDI	Rockweed	OBL	Algae	yes			
Galium aparine	GAAP	Cleavers bedstraw	FACU	Herb	yes	yes	hairy nutlets	
Galium spp	GASP	Pacific bedstraw; cleavers; small bedstraw	mixed	Herb	yes			
Galium trifidum	GATR3	small bedstraw	FACW+	Herb	yes		smooth nutlets, smaller than var. pacificum	
Galium trifidum var. pacificum; *Galium trifidum* L. spp. *columbianum*	GATR	Pacific bedstraw	FACW	Herb	yes		smooth nutlets	
Galium triflorum	GATR2	fragrant bedstraw	FACU	Herb	yes		hairy nutlets, usually partial shade	

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Gaultheria shallon	GASH	Salal	FACU	Shrub	yes			
Geum macrophyllum	GEMA	Largeleaf avens	FACW-	Herb	yes			
Glaux maritima	GLMA	sea milkwort	FACW+	Herb	yes			
Glechoma hederacea	GLHE	Creeping Charlie	FACU+	Herb	no	yes		
Glyceria grandis	GLGR	American mannagrass	OBL	Grass	yes			
Glyceria striata	GLST	Fowl mannagrass	OBL	Grass	yes		formerly *G. elata*	GLEL
Gnaphalium uliginosum	GNUL	Marsh cudweed	FAC+	Herb	no			
Gratiola ebracteata	GREB	bractless hedgehyssop	OBL	Herb	yes			
Gratiola neglecta	GRNE	American Hedge-hyssop	OBL	Herb	yes			
Hedera helix	HEHE	English ivy	UPL	Herb	no	yes		
Helenium autumnale	HEAU	common sneezeweed	FACW	Herb	yes			
Heracleum maximum	HEMA	Cow-parsnip	FAC+	Herb	yes		formerly *Heracleum lanatum*	HELA
Holcus lanatus	HOLA	Common velvetgrass	FAC	Grass	no			
Hordeum brachyantherum	HOBR	Meadow barley	FACW-	Grass	yes			
Hydrocotyle ranunculoides	HYRA2	Water pennywort	OBL	Herb	yes			
Hypericum scouleri	HYSC	Western St. Johns wort	FAC	Herb	yes		also called *Hypericum formosum*	HYFO
Ilex aquifolium	ILAQ	English holly	UPL	Tree	no			
Ilex sp.	ILSP	Holly	UPL	Tree	no			
Impatiens capensis,Impatiens noli-tangere	IMSP	Spotted touch-me-not, Common touch-me-not	FACW	Herb	yes			
Iris pseudacorus	IRPS	Yellow iris	OBL	Herb	no			
Juncus acuminatus	JUAC	Tapertip rush	OBL	Rush	yes			
Juncus arcticus Wild. ssp. *littoralis*	JUAR	mountain rush	No	Rush	yes		formerly *Juncus balticus*, Baltic rush	JUBA
Juncus bufonius	JUBU	Toad rush	FACW	Rush	yes			
Juncus effusus	JUEF	Soft rush	FACW	Rush	mixed			
Juncus ensifolius	JUEN	Daggerleaf rush	FACW	Rush	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Juncus falcatus	JUFA	Sickleleaf rush	FACW-	Rush	yes			
Juncus gerardii	JUGE	saltmeadow rush	FACW+	Rush	yes			
Juncus nevadensis	JUNE	Sierra rush	FACW	Rush	yes			
Juncus oxymeris	JUOX	Pointed rush	FACW+	Rush	yes			
Juncus spp.	JUSP	Rush	mixed	Rush	mixed			
Juncus supiniformis	JUSU	Spreading rush	OBL	Rush	yes			
Juncus tenuis	JUTE	slender rush, poverty rush	FACW-	Rush	yes			
Lathyrus palustris	LAPA	Marsh peavine	OBL	Herb	yes			
Leersia oryzoides	LEOR	Rice cutgrass	OBL	Grass	yes			
Lemna minor	LEMI	Duckweed	OBL	Herb	yes			
Leucanthemum vulgare	LEVU	oxeye daisy	UPL	Herb	no	yes		
Leymus mollis	LEMO	American dunegrass	UPL	Grass	yes			
Lilaeopsis occidentalis	LIOC	Western lilaeopsis	OBL	Herb	yes			
Limosella aquatica	LIAQ	Water mudwort	OBL	Herb	yes			
Lonicera involucrata	LOIN	Black twinberry	FAC+	Shrub	yes			
Lotus corniculatus	LOCO	Birdsfoot trefoil	FAC	Herb	no			
Ludwigia palustris	LUPA	False loosestrife	OBL	Herb	yes			
Lupinus polyphyllus	LUPO	Large-leaved lupine	FAC+	Herb	yes			
Lycopus americanus	LYAM2	American water horehound	OBL	Herb	yes			
Lycopus sp.	LYSP	Bugleweed; horehound	OBL	Herb	yes			
Lycopus uniflorus	LYUN	Northern bugleweed	OBL	Herb	yes			
Lysichiton americanus	LYAM	Skunk cabbage	OBL	Herb	yes			
Lysimachia nummularia	LYNU	Moneywort, Creeping Jenny	FACW	Herb	no			
Lythrum salicaria	LYSA	Purple loosestrife	FACW+	Herb	no	yes		
Madia sativa	MASA	coast tarweed	UPL	Herb	yes			
Maianthemum dilatatum	MADI	Wild lily-of-the-valley	FAC	Herb	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Maianthemum racemosum	MARA	Large false lily of the valley	UPL	Herb	yes		formerly *Smilacina racemosa*	SMRA
Malus fusca	MAFU	Pacific crab apple	FACW	Tree	yes			
Marchantia polymorpha	MAPO	Lung liverwort	na	NV	yes			
Mentha arvensis	MEAR	wild mint	FACW-	Herb	yes		pointy serrations	
Mentha spicata L.	MESP3	spearmint	OBL	Herb	no		rounded serrations	
Mentha spp.	MESP	Mint (field mint, spearmint)	mixed	Herb	mixed			
Mimulus alsinoides	MIAL	Chickweed monkey-flower	OBL	Herb	yes			
Mimulus guttatus	MIGU	Yellow monkeyflower	OBL	Herb	yes			
Mimulus lewisii	MILE	great purple monkey flower	FACW+	Herb	yes			
Mimulus ringens	MIRI	Allegheny monkeyflower	OBL	Herb	yes			
Mitella trifida	MITR	Three-toothed mitrewort	na	Herb	yes			
Myosotis laxa	MYLA	Small forget-me-not	OBL	Herb	yes			
Myosotis laxa, M. scorpioides	MYSP	Small forget-me-not, Common forget-me-not	mixed	Herb	mixed			
Myosotis scorpioides	MYSC	Common forget-me-not	FACW	Herb	no			
Myriophyllum aquaticum	MYAQ	Parrot-feather milfoil	OBL	Herb	no	yes	SAV	
Myriophyllum hippuroides	MYHI	western milfoil	OBL	Herb	yes		SAV	
Myriophyllum sibiricum	MYSI	northern milfoil, short spike milfoil	OBL	Herb	yes		SAV	
Myriophyllum spicatum	MYSP3	Eurasian water milfoil	OBL	Herb	no	yes	SAV	
Myriophyllum spp.	MYSP2	Milfoil	OBL	Herb	mixed			
Nuphar lutea	NULU	Yellow pond-lily	OBL	Herb	yes			
Oemleria cerasiformis	OECE	Indian-plum	FACU	Shrub	yes			
Oenanthe sarmentosa	OESA	Water parsley	OBL	Herb	yes			
Oxalis oregana	OXOR	Redwood sorrel	UPL	Herb	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Panicum capillare	PACA	witchgrass	FACU+	Grass	yes			
Panicum occidentale/Dichanthelium acuminatum	PAOC	western panicgrass	FACW	Grass	yes			
Parentucellia viscosa	PAVI	Yellow parentucellia	FAC-	Herb	no			
Paspalum distichum	PADI	Knotgrass	FACW	Grass	yes			
Pellia neesiana	PENE	Ring pellia		Liverwort	yes			
Phacelia hastata	PHHA	silver-leaf phacelia	UPL	Herb	yes			
Phalaris arundinacea	PHAR	Reed canary-grass	FACW	Grass	no	yes		
Physocarpus capitatus	PHCA	Pacific ninebark	FACW-	Shrub	yes			
Picea sitchensis	PISI	Sitka spruce	FAC	Tree	yes			
Plantago lanceolata var. lanceolata	PLLA	Rib plantain	FAC	Herb	no			
Plantago major	PLMA	common plantain	FACU+	Herb	no			
Platanthera dilatata	PLDI	white bog orchid	FACW+	Herb	yes			
Poa annua	POAN2	annual bluegrass	FAC	Grass	no			
Polygonum amphibium	POAM	water ladysthumb, water smartweed	OBL	Herb	yes			
Polygonum hydropiper, P. hydropiperoides	POHY	Waterpepper, mild waterpepper, swamp smartweed	OBL	Herb	mixed			
Polygonum lapathifolium	POLA	curly top knotweed	FACW	Herb	yes			
Polygonum persicaria	POPE	Spotted ladysthumb	FACW	Herb	no	yes		
Polygonum sp.	POSP	Knotweed, Smartweed	mixed	Herb	mixed			
Polypodium glycyrrhiza	POGL	Licorice fern	FACU	Fern	yes			
Polystichum munitum	POMU	Sword fern	FACU	Fern	yes			
Populus balsamifera	POBA	black cottonwood	FAC	Tree	yes			
Potamogeton crispus	POCR	Curly leaf pondweed	OBL	Herb	no	yes	SAV	
Potamogeton natans	PONA	Floating-leaved pondweed	OBL	Herb	yes		SAV	
Potamogeton pusillus	POPU	Small pondweed	OBL	Herb	yes		SAV	
Potamogeton richardsonii	PORI	Richardson's pondweed	OBL	Herb	yes		SAV	

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Potamogeton sp.	POSP2	Pondweed	OBL	Herb	mixed			
Potamogeton zosteriformis	POZO	Eelgrass pondweed	OBL	Herb	yes		SAV	
Potentilla anserina ssp. Pacifica/Argentina egedii ssp. Egedii	POAN	Pacific silverweed	OBL	Herb	yes		also known as *Argentina egedii spp. Egedii*	
Prunella vulgaris	PRVU	Self heal	FACU+	Herb	yes			
Prunus emarginata	PREM	Bitter cherry	FACU	Tree	yes			
Pseudognaphalium canescens	PSCA	Slender cudweed; Wright's cudweed	UPL	Herb	yes		formerly *Gnaphalium microcephalum*	GNMI
Pteridium aquilinum	PTAQ	Bracken fern	FACU	Fern	yes			
Puccinellia pumila	PUPU	dwarf alkaligrass	FACW+	Herb	yes			
Ranunculus cymbalaria	RACY	Alkali buttercup	OBL	Herb	yes			
Ranunculus flammula	RAFL	Small creeping buttercup	FACW	Herb	yes			
Ranunculus repens	RARE	Creeping buttercup	FACW	Herb	no			
Ranunculus sceleratus	RASC	Celery-leaved buttercup	OBL	Herb	yes			
Ranunculus uncinatus	RAUN	Woodland buttercup	FAC-	Herb	yes			
Ribes bracteosum	RIBR	Stink currant	FAC	Shrub	yes			
Ribes divaricatum	RIDI	Wax currant, coast black currant	FAC	Shrub	yes			
Ribes lacustre	RILA	Swamp gooseberry	FAC+	Shrub	yes			
Riccia fluitans	RIFL	Liverwort	na	Liverwort	yes			
Ricciocarpos natans	RINA	Purple fringed liverwort	na	Liverwort	yes			
Rorippa calycina, R.curvisiliqua	ROSP	Yellow cress	mixed	Herb	yes			
Rorippa columbiae	ROCO	Columbian yellowcress	OBL	Herb	yes		Threatened in Washington state	ROCA
Rorippa curvisiliqua	ROCU	curvepod yellow cress	OBL	Herb	yes			
Rorippa nasturtium-aquaticum/Nasturtium officinale	RONA	Watercress	OBL	Herb	no			
Rorippa palustris	ROPA	Marsh yellow-cress	OBL	Herb	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Rosa nutkana	RONU	Nootka rose	FAC	Shrub	yes			
Rosa pisocarpa	ROPI	Clustered wild rose, peafruit rose, swamp rose	FAC	Shrub	yes			
Rubus armeniacus	RUAR	Himalayan blackberry	FACU	Shrub	no		formerly *Rubus discolor*	RUDI
Rubus laciniatus	RULA	Evergreen blackberry	FACU+	Shrub	no			
Rubus parviflorus	RUPA	Thimbleberry	FAC-	Shrub	yes			
Rubus spectabilis	RUSP	Salmonberry	FAC+	Shrub	yes			
Rubus ursinus	RUUR	Trailing blackberry	FACU	Shrub	yes			
Rumex acetosella	RUAC	common sheep sorrel	FACU+	Herb	no	yes		
Rumex aquaticus	RUAQ	Western dock	FACW+	Herb	yes		formerly *Rumex occidentalis*	RUOC
Rumex crispus	RUCR	Curly dock	FAC+	Herb	no			
Rumex maritimus	RUMA	Golden dock, seaside dock	FACW+	Herb	yes			
Ruppia maritima	RUMA2	Widgeongrass	OBL	Herb	yes		SAV	
Sagittaria latifolia	SALA	Wapato	OBL	Herb	yes			
Salicornia depressa	SADE	pickleweed	OBL	Herb	yes		formerly *Salicornia virginica*	SAVI
Salix fluviatilis	SAFL	Columbia River willow, river willow	OBL	Shrub	yes			
Salix lucida	SALU	Pacific willow	FACW+	Shrub	yes			
Salix sitchensis	SASI	Sitka willow	FACW	Shrub	yes			
Salix spp.	SASP	Willow	mixed	Shrub	yes			
Sambucus racemosa	SARA	Red elderberry	FACU	Shrub	yes			
Schoenoplectus acutus	SCAC	Hardstem bulrush, tule	OBL	Sedge	yes		formerly *Scirpus acutus*	SCAC
Schoenoplectus americanus	SCAM	American bulrush, threesquare bulrush	OBL	Sedge	yes		formerly *Scirpus americanus*	SCAM

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Schoenoplectus maritimus	SCMA	Seacoast bulrush	OBL	Sedge	yes		formerly *Scirpus maritimus*	SCMA
Schoenoplectus spp.	SCSP	hybrid sedge	OBL	Sedge	mixed		used when spp appears to have hybridized or has no identifying features	
Schoenoplectus tabernaemontani	SCTA	Softstem bulrush, tule	OBL	Sedge	Yes		formerly *Scirpus lacustris*	SCLA
Schoenoplectus triqueter	SCTR	Threesquare tule	OBL	Sedge	no		formerly *Scirpus triqueter*	SCTR
Scirpus cyperinus	SCCY	woolly sedge	OBL	Sedge	yes			
Scirpus microcarpus	SCMI	Small-fruited bulrush	OBL	Sedge	yes			
Scrophularia lanceolata	SCLA	Lance-leaf figwort	FAC	Herb	yes		formerly SCLA2	SCLA2
Sium suave	SISU	Hemlock waterparsnip	OBL	Herb	yes			
Solanum dulcamara	SODU	Bittersweet nightshade	FAC+	Herb	no			
Solidago canadensis	SOCA	Canada goldenrod	FACU	Herb	yes			
Sparganium angustifolium	SPAN	Narrowleaf burreed	OBL	Herb	yes			SPEM
Spiraea douglasii	SPDO	Douglas spiraea	FACW	Shrub	yes			
Stachys cooleyae	STCO	Cooley's hedge-nettle	FACW	Herb	yes			
Stellaria crispa	STCR	Curled starwort	FAC+	Herb	yes			
Stellaria longifolia	STLO	Longleaf starwort	FACW	Herb	yes			
Symphoricarpos albus	SYAL	Common snowberry	FACU	Shrub	yes			
Symphyotrichum subspicatum	SYSU	Douglas aster	FACW	Herb	yes		formerly *Aster subspicatus*	ASSU
Taraxacum officinale	TAOF	Common dandelion	FACU	Herb	no			
Tellima grandiflora	TEGR	Fringe cup	UPL	Herb	yes			
Thuja plicata	THPL	Western redcedar	FAC	Tree	yes			
Tiarella trifoliata	TITR	Foamflower	FAC-	Herb	yes			
Tolmiea menziesii	TOME	Piggy-back plant	FAC	Herb	yes			

Table B.1. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/ Weedy	NOTES	Previous Species Code
Toxicodendron diversilobum	TODI	Pacific poison oak	UPL	Shrub	yes		upland area of Water Resources Center	
Trifolium arvense	TRAR	rabbitfoot clover	UPL	Herb	no	yes		
Trifolium pratense, T. repens, T. dubium	TRSP	Red clover, white clover, small hop-clover	mixed	Herb	no			
Trifolium wormskioldii	TRWO	Springbank clover	FACW+	Herb	yes			
Triglochin maritima	TRMA	Seaside arrowgrass	OBL	Arrow-grass	yes			
Typha angustifolia	TYAN	Narrowleaf cattail	OBL	Herb	no			
Typha angustifolia, T. latifolia	TYSP	Narrowleaf cattail, common cattail	OBL	Herb	mixed			
Typha latifolia	TYLA	Common cattail	OBL	Herb	yes			
Urtica dioica	URDI	Stinging Nettle	FAC+	Herb	yes			
Vaccinium parvifolium	VAPA	Red huckleberry	FACU	Shrub	yes			
Veratrum californicum	VECA	California false hellebore	FACW+	Herb	yes			
Verbascum thapsus	VETH	Common mullein	UPL	Herb	no		upland area of Water Resources Center	
Veronica americana	VEAM	American speedwell	OBL	Herb	yes			
Veronica anagallis-aquatica	VEAN	water speedwell	OBL	Herb	yes			
Veronica scutellata	VESC	marsh speedwell	OBL	Herb	yes			
Veronica spp.	VESP	speedwell	OBL	Herb	yes			
Viburnum edule	VIED	Highbush cranberry	FACW	Shrub	yes			
Vicia americana	VIAM	American vetch	FAC	Herb	yes			
Vicia spp	VISP	Vetch	mixed	Herb	mixed			
Wolffia spp.	WOSP	Watermeal	OBL	Herb	yes			
Xanthium strumarium	XAST	rough cocklebur	FAC	Herb	yes			
Zannichellia palustris	ZAPA	horned pondweed	OBL	Herb	yes		SAV	
Zostera japonica	ZOJA	Japanese eelgrass	OBL	Herb	no			NAJA

Table B.2. Plant species observed by researchers other than PNNL during restoration monitoring that were not already included in the PNNL species list (Table B.1).

Scientific Name	Code	Common Name	Wetland Indicator Status	Categor y	Native	Invasive/Weedy	Notes	Previous Species Code
Species observed at restoration sites								
Abies grandis	ABGR	Grand fir	FACU-*	Tree	yes			
Acer macrophyllum	ACMA	Bigleaf maple	FACU	Tree	yes			
Acer sp.	ACSP	maple	mixed	mixed	yes			
Achillea millefolium	ACMI	common yarrow	FACU	Herb	NI			
Agrostis scabra	AGSC	Rough bentgrass	FAC	Grass	yes			
Agrostis sp.	AGSP	bentgrass	mixed	Grass	mixed	mixed		
Aira praecox	AIPR	yellow hairgrass	NA	Grass	no			
Alisma sp.	ALSP	water plantain	OBL	Herb	mixed			
Alopecurus geniculatus	ALGE	water foxtail, water fescue	OBL	Grass	no			
Alopecurus sp.	ALSP2	foxtail	mixed	Grass	mixed			
Amsinckia sp.	AMSP	fiddlehead	mixed	Herb	yes			
Anagallis arvensis	ANAR2	Scarlet pimpernel	FAC	Herb	no			
Anthemis cotula	ANCO	stinking chamomile, dogfennel	FACU	Herb	no			
Avena sp.	AVSP	Oat	NA	Grass	no			
Bidens sp.	BISP	beggartick	mixed	Herb	mixed			
Bromus hordeaceus	BRHO	soft brome	UPL	Grass	no			
Bromus sitchensis	BRSI	Alaska brome	NA	Grass	yes			
Callitriche sp.	CASP3	water-starwort	OBL	Herb	mixed			
Callitriche stagnalis	CAST2	pond water-starwort	OBL	Herb	no			
Cichorium intybus	CIDO2	chicory	NA	Herb	no			
Cirsium sp.	CISP	Cirsium species	mixed	Herb	mixed			
Collomia grandiflora	COGR	Grand collomia	NA	Herb	yes			
Conyza canadensis	COCA2	Canadian horseweed	FACU	Herb	yes			

Table B.2. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/Weedy	Notes	Previous Species Code
Coreopsis tinctoria var. atkinsoniana	COAT	Atkinson's tickeseed	FACU	Herb	yes			
Cornus nuttallii	CONU	Pacific dogwood	NA	Tree	yes			
Crataegus monogyna	CRMO	common hawthorn	FACU+	Shrub	no		can hybridize with *C. douglasii*	
Crepis capillaris	CRCA	smooth hawksbeard	FACU*	Herb	no			
Crepis setosa	CRSE	rough hawksbeard, bristly hawksbeard	NA	Herb	no			
Crepis sp.	CRSP	hawksbeard	mixed	Herb	no			
Cytisus scoparius	CYSC	scotch broom	NA	Shrub	no	yes		
Danthonia sp.	DASP	Oatgrass	mixed	Grass	mixed			
Daucus carota	DACA	Queen Anne's lace, wild carrot	NA	Herb	no	yes		
Deschampsia elongata	DEEL	Slender hairgrass	FACW-	Grass	yes			
Dipsacus fullonum	DIFU	Fuller's teasel	FAC	Herb	no			
Dipsacus sp.	DISP2	teasel	mixed	Herb	mixed			
Downingia sp.	DOSP	calicoflower	mixed	Herb	yes			
Echinochloa crus-galli	ECCR	barnyardgrass	FACW	Grass	no			
Echinochloa muricata	ECMU	Rough barnyardgrass	FACW	Grass	yes			
Elymus glaucus	ELGL	blue wildrye	FACU	Grass	yes			
Elymus hirsutus	ELHI	northern ryegrass	NA	Grass	yes			
Elymus sp.	ELSP2	wildrye	mixed	Grass	mixed			
Epilobium sp.	EPSP	Epilobium species	mixed	Herb	mixed			
Erodium cicutarium	ERCI	redstem stork's bill	NA	Herb	no			
Festuca sp.	FESP	Fescue	mixed	Grass	mixed			
Geranium robertianum	GERO	herb-robert, stinky bob, robert geranium	NA	Herb	no	yes		
Geranium sp.	GESP	geranium	mixed	Herb	mixed			
Gilia capitata	GICA	bluehead gilia	NA	Herb	yes			

Table B.2. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/Weedy	Notes	Previous Species Code
Gnaphalium palustre	GNPA	western marsh cudweed	FAC+	Herb	yes			
Gnaphalium sp.	GNSP	cudweed	FAC+	Herb	mixed			
Holcus sp.	HOSP	velvetgrass	mixed	Grass	no			
Holodiscus discolor	HODI	Ocean-spray	NA	Shrub	yes			
Hydrocotyle umbellata	HYUM	manyflower marshpennywort	OBL	Herb	yes			
Hypericum anagalloides	HYAN	Tinker's penny	OBL	Herb	yes			
Hypericum sp.	HYSP	St. John's wort	mixed	Herb	mixed			
Iris tenax	IRTE	Toughleaf iris	NA	Herb	yes			
Juncus articulatus	JUAR2	jointleaf rush	OBL	Rush	yes			
Juncus effusus var. effusus	JUEF 3	Soft rush	FACW	Rush	no			
Juncus effusus var. pacificus	JUEF 2	Soft rush	FACW	Rush	yes			
Juncus mertensianus	JUME	Merten's rush	OBL	Rush	yes			
Lactuca serriola	LASE	prickly lettuce	FACU	Herb	no			
Lactuca sp.	LASP	lettuce	mixed	Herb	mixed			
Lolium sp.	LOSP	ryegrass	mixed	Grass	no			
Lotus sp.	LOSP2	trefoil	mixed	Herb	mixed			
Ludwigia sp.	LUSP	Primrose-willow	mixed	Herb	mixed			
Lupinus sp.	LUSP2	Lupine	mixed	Herb	yes			
Lythrum portula	LYPO	Spatulaleaf loosestrife	NI	Herb	no			
Mahonia aquifolium	MAAQ	tall Oregongrape	NA	Shrub	yes			
Mahonia nervosa	MANE	Cascade Oregongrape	NA	Shrub	yes			
Mentha pulegium	MEPU	pennyroyal	OBL	Herb	no			
Myosotis discolor	MYDI	changing forget-me-not	FACW	Herb	no			
Nuphar polysepala	NUPO	Rocky Mountain pond-lily	OBL	Herb	yes			
Oenothera biennis	OEBI	common evening primrose	FACU	Herb	yes			

Table B.2. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/Weedy	Notes	Previous Species Code
Pedicularis oederi	PEOE	Oeder's lousewort	NA	Herb	yes			
Philadelphus lewisii	PHLE	mock orange	NA	Shrub	yes			
Phleum pratense	PHPR	timothy	FAC-	Grass	no			
Picea sp.	PISP	spruce	mixed	Tree	yes			
Plagiobothrys figuratus	PLFI	fragrant popcorn flower	FACW	Herb	yes			
Plantago sp.	PLSP	plantain	mixed	Herb	mixed			
Poa sp.	POSP4	bluegrass	mixed	Grass	mixed			
Polygonum aviculare	POAV	prostrate knotweed, yard knotweed, common knotweed	FACW-	Herb	no			
Potentilla sp.	POSP3	Cinquefoil	mixed	Herb	mixed			
Prunus sp.	PRSP	cherry	mixed	Tree	mixed			
Pseudognaphalium stramineum	PSST	cottonbatting plant	FAC+	Herb	yes			
Pseudotsuga menziesii	PSME	Douglas fir	FACU*	Tree	yes			
Quercus garryana	QUGA	Oregon white oak	NA	Tree	yes			
Ranunculus sp.	RASP	buttercup	mixed	Herb	mixed			
Ribes sanguineum	RISA	red-flowering currant	NA	Shrub	yes			
Ribes sp.	RISP	currant	mixed	Shrub	mixed			
Robinia sp.	ROSP2	locust	mixed	Tree	yes			
Rosa gymnocarpa	ROGY	Baldhip rose	FACU	Shrub	yes			
Rosa sp.	ROSP3	rose	mixed	Shrub	mixed			
Rumex conglomeratus	RUCO	Clustered dock, Sharp dock	FACW	Herb	no			
Rumex obtusifolius	RUOB	bitter dock	FAC	Herb	no			
Rumex sp.	RUSP2	dock	mixed	Herb	mixed			
Sagittaria cuneata	SACU	arumleaf arrowhead	OBL	Herb	yes			
Salix hookeriana	SAHO	dune willow, coastal willow	FACW-	Shrub	yes			

Table B.2. (contd)

Scientific Name	Code	Common Name	Wetland Indicator Status	Category	Native	Invasive/Weedy	Notes	Previous Species Code
Salix piperi	SAPI	Piper willow	FACW-	Shrub	yes			
Salix scouleriana	SASC	Scouler's willow	FAC	Shrub	yes			
Sambucus cerulea	SACE	blue elderberry	FACU	Shrub	yes			
Sambucus sp.	SASP2	elderberry	FACU	Shrub	yes			
Schedonorus phoenix	SCPH	tall fescue	FAC-	Grass	no			
Scirpus sp.	SCSP2	Scirpus species	mixed	Sedge	mixed			
Scutellaria angustifolia	SCAN	Narrowleaf skullcap	NA	Herb	yes			
Senecio jacobaea	SEJA	Stinking willie, tansy ragwort	FACU	Herb	yes	yes		
Senecio sp.	SESP	ragwort	mixed	Herb	mixed			
Sisymbrium officinale	SIOF	hedgemustard	NA	Herb	no			
Solanum nigrum	SONI	Black nightshade	FACU	Herb	no			
Solanum sp.	SOSP	Nightshade	mixed	Herb	mixed			
Sonchus sp.	SOSP2	sowthistle	mixed	Herb	no	mixed		
Stellaria calycantha	STCA	northern starwort	FACW+	Herb	yes			
Stellaria media	STME	common chickweed	FACU	Herb	no			
Tanacetum sp.	TASP	tansy	mixed	Herb	mixed			
Tanacetum vulgare	TAVU	common tansy	NI	Herb	no	yes		
Trifolium grandiflorum	TRGR	large-flower hop clover	NA	Herb	NA			
Trifolium repens	TRRE	white clover	FAC*	Herb	no			
Triticum sp.	TRSP2	wheat	NA	Grass	no			
Tsuga heterophylla	TSHE	Western hemlock	FACU-	Tree	yes			
Verbascum blattaria	VEBL	moth mullein	UPL	Herb	no			
Vicia sativa	VISA	garden vetch	UPL	Herb	no			
Vicia tetrasperma	VITE	lentil vetch	NA	Herb	no			
Vulpia bromoides	VUBR	brome fescue	NI	Grass	no			
Vulpia octoflora	VUOC	sixweeks fescue	UPL	Grass	yes			

Appendix C

Site Maps

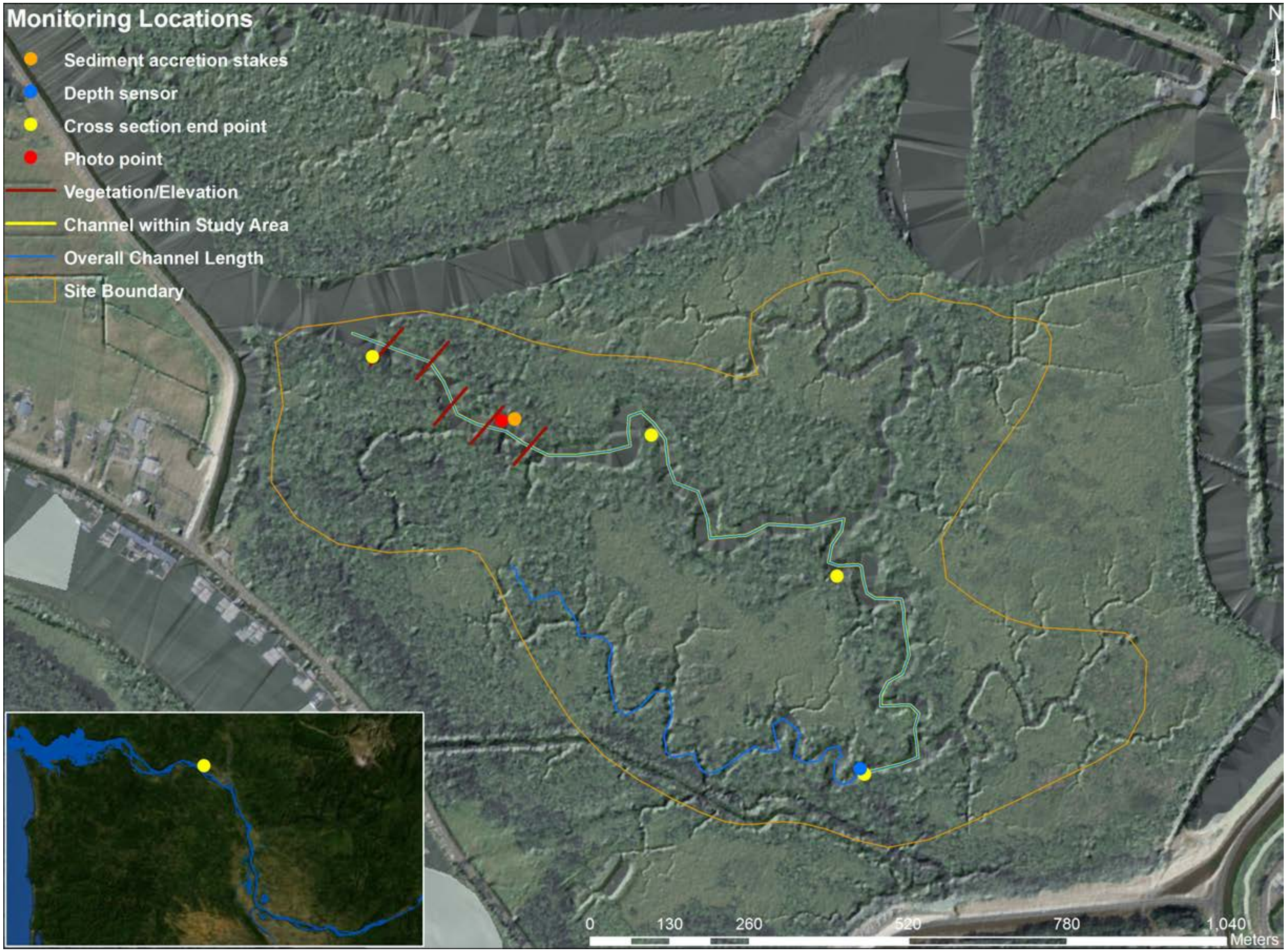


Figure A.1. Map showing the Coal Creek Riparian Wetland site.

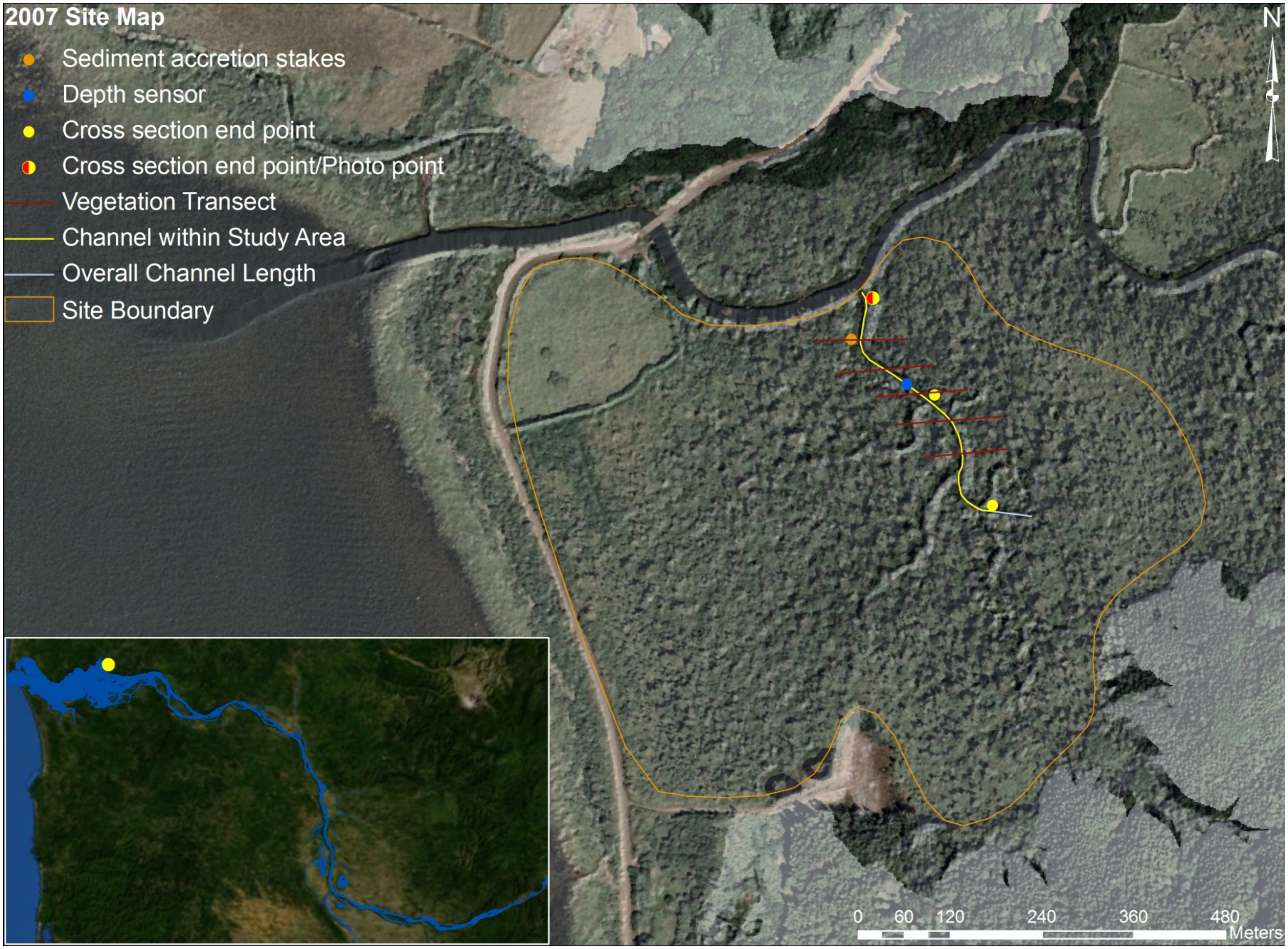


Figure A.2. Map showing the Crooked Creek Swamp site.

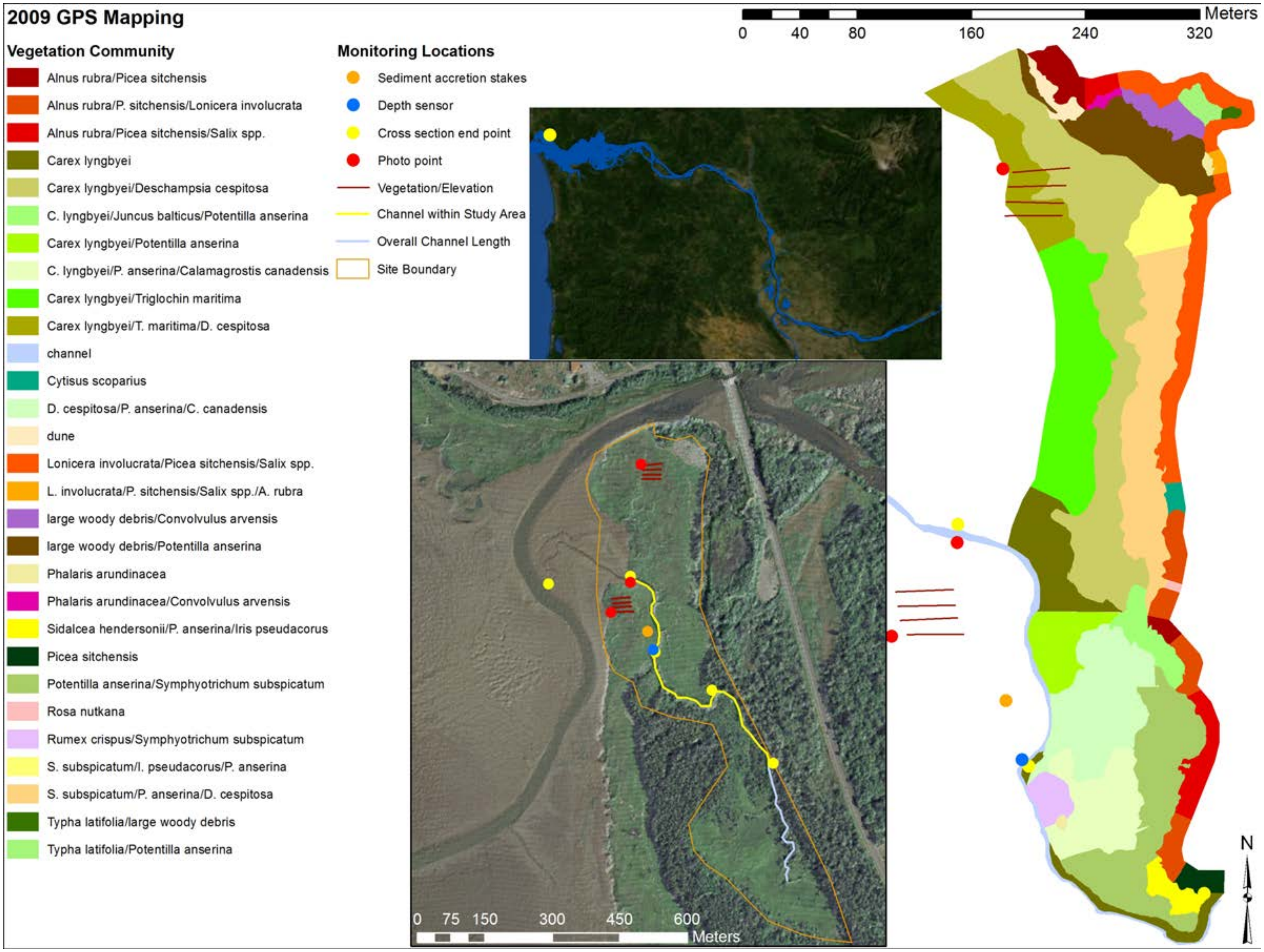


Figure A.3. Map showing the Chinook River Marsh site.

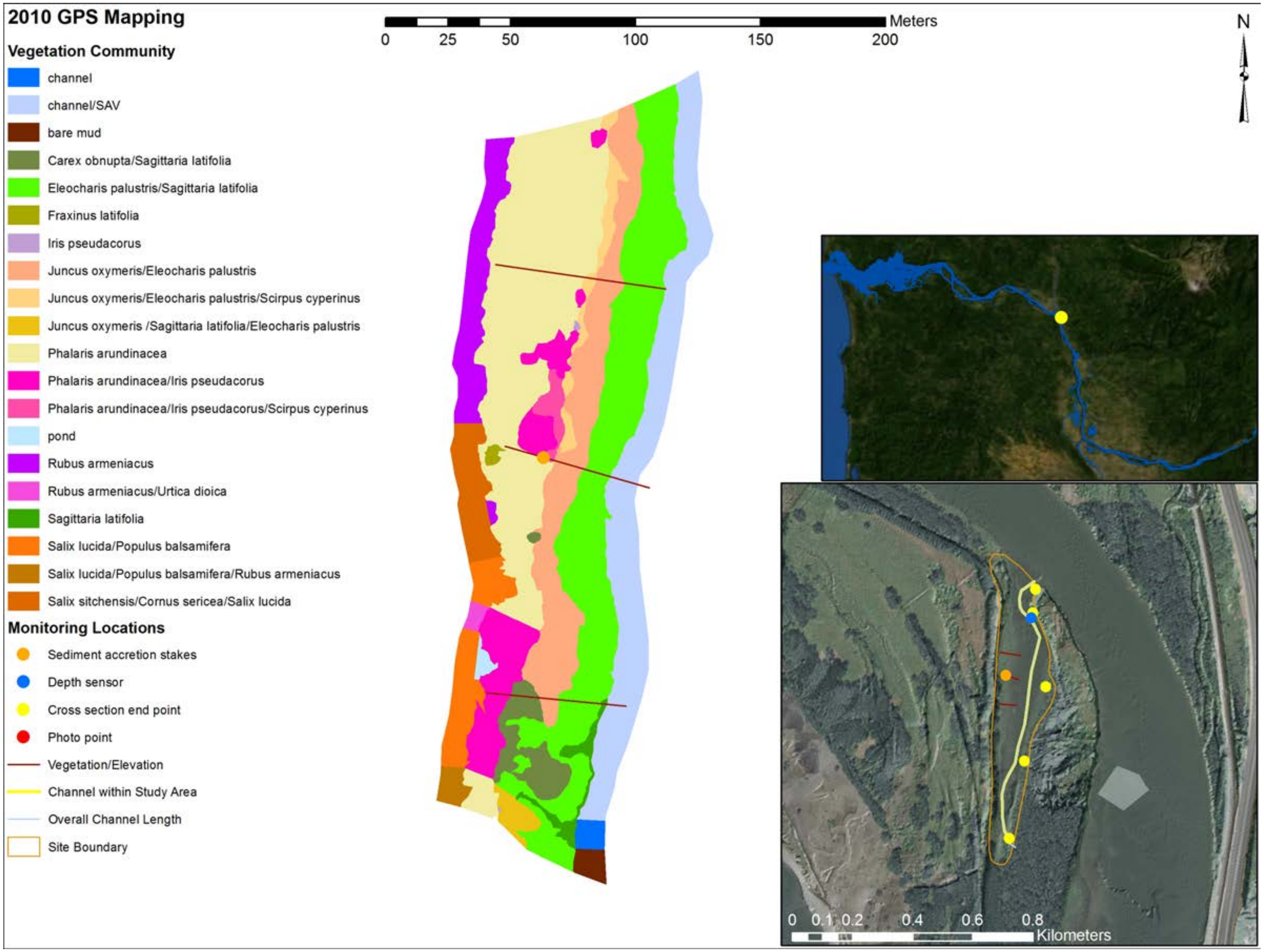


Figure A.4. Map showing the Cottonwood Island 1 Marsh site.

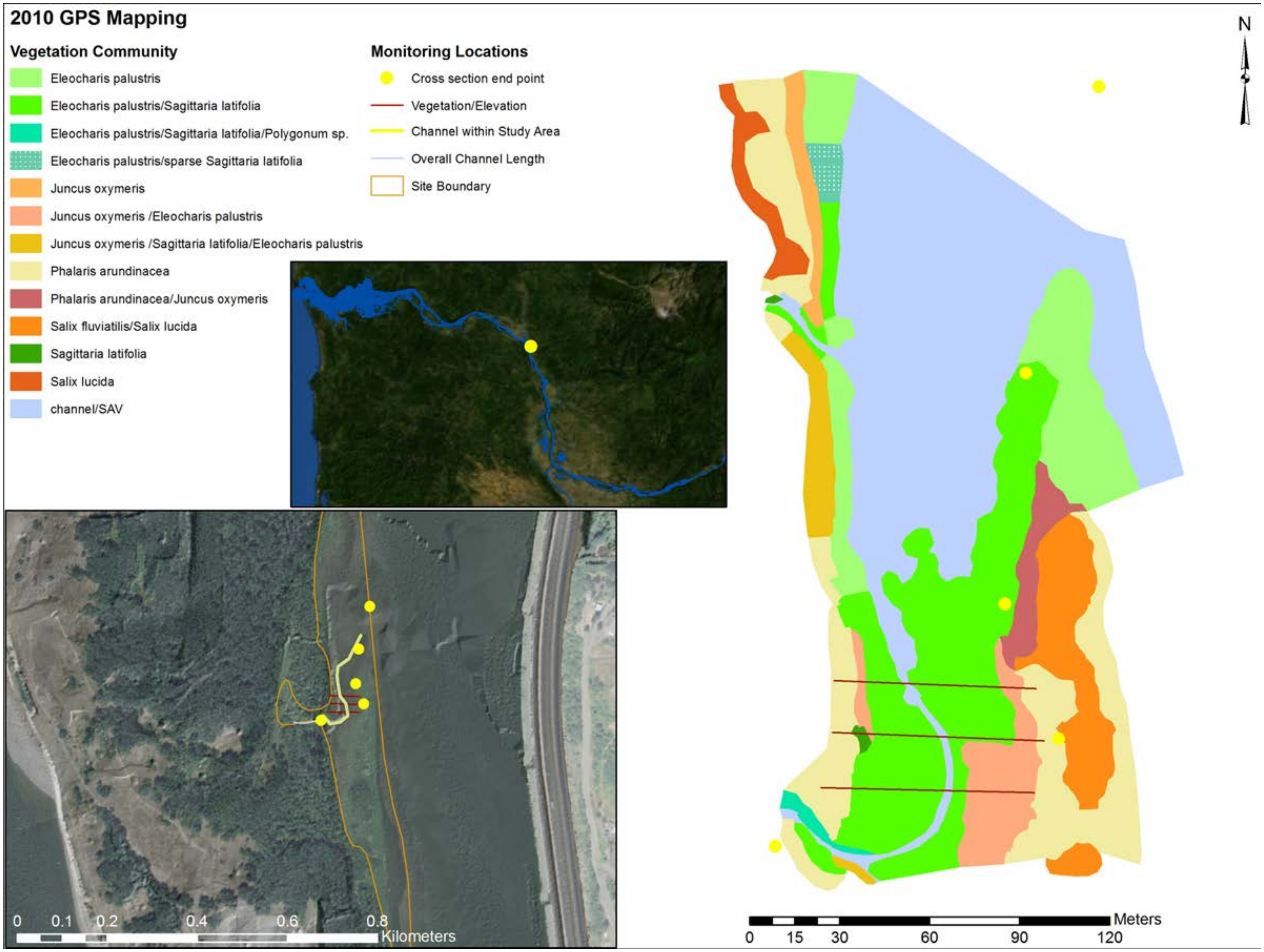


Figure A.5. Map showing the Cottonwood Island 2 Marsh site.

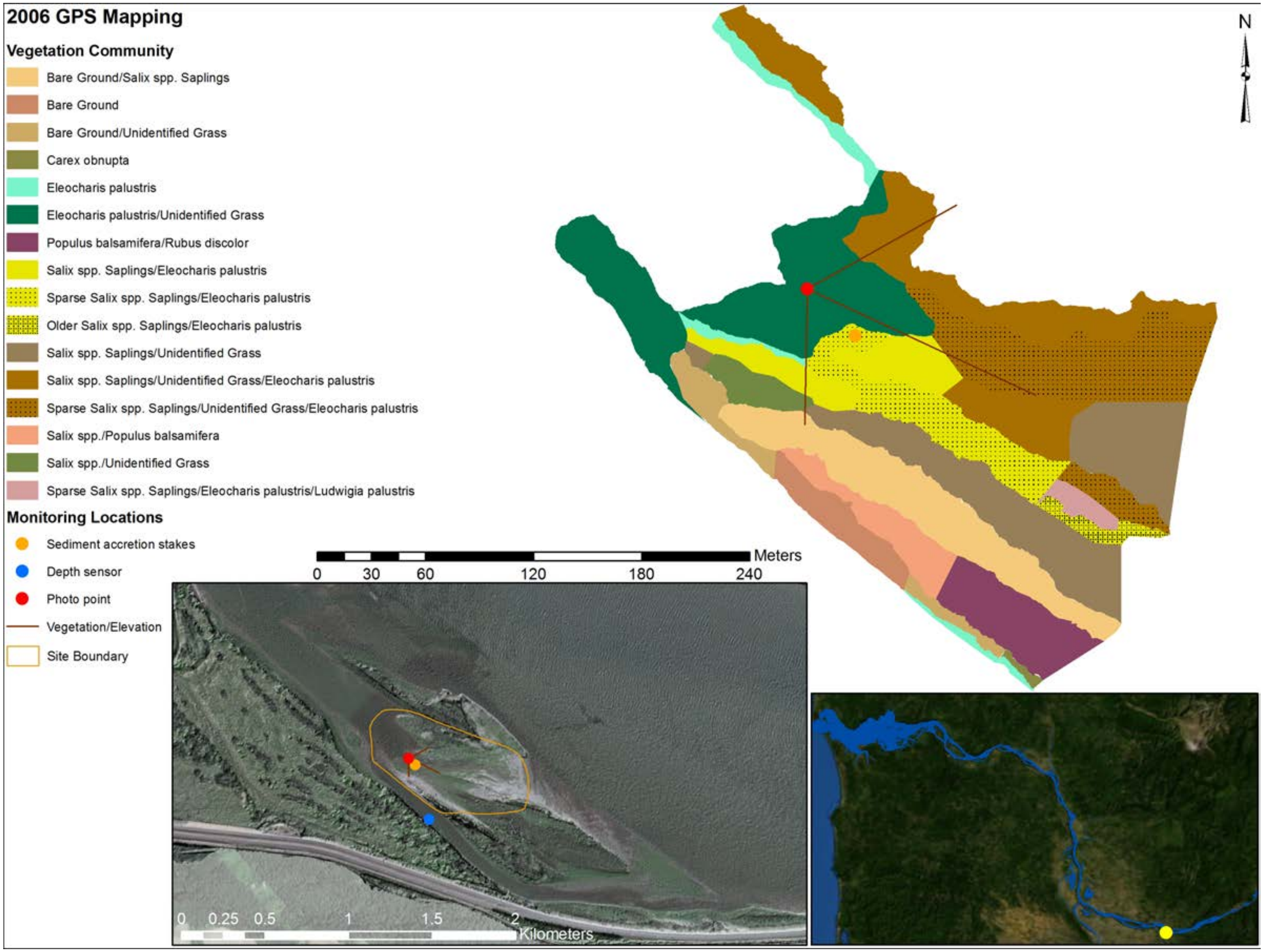


Figure A.6. Map showing the Chatham Island Marsh site.

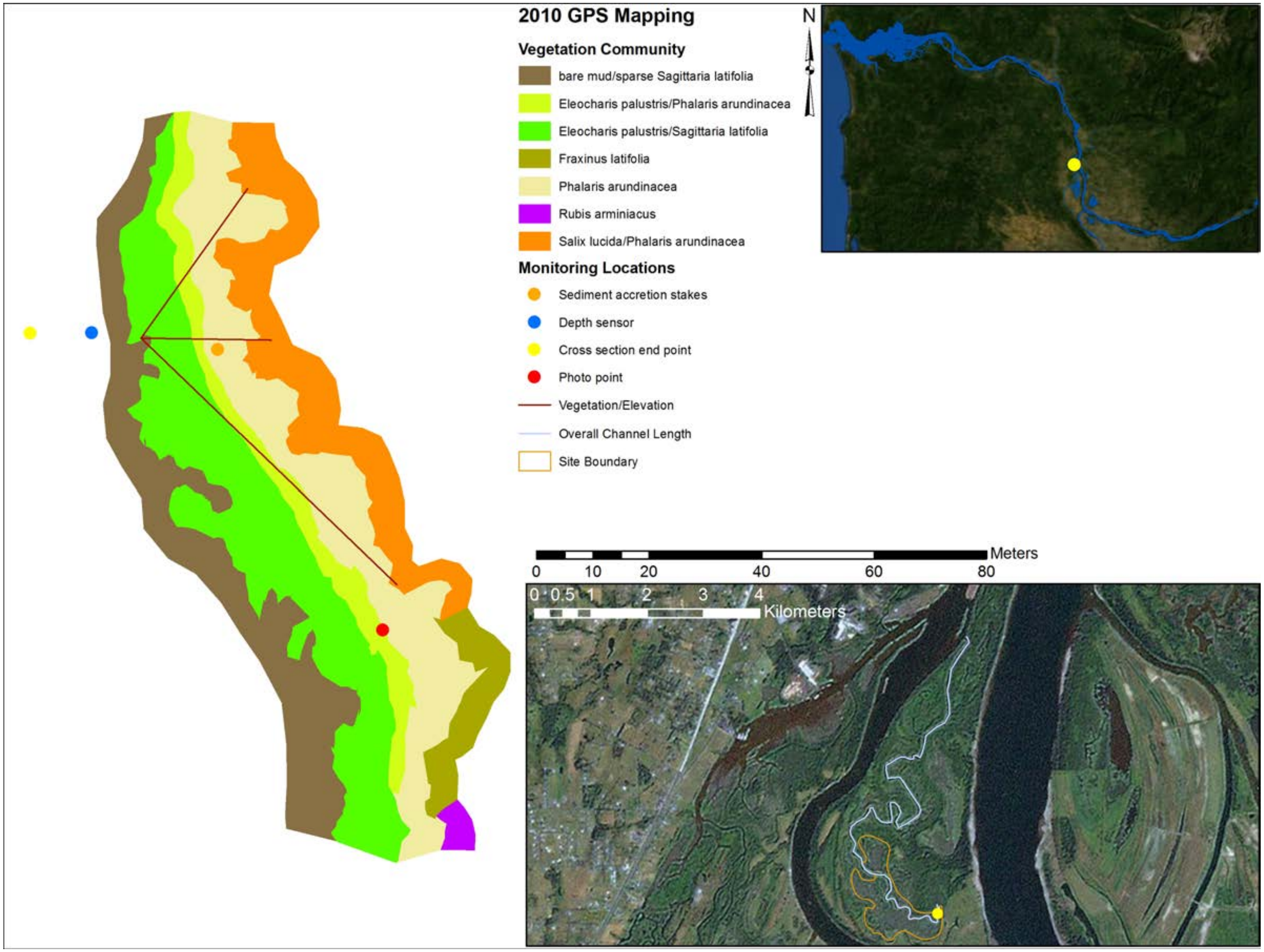


Figure A.7. Map showing the Cunningham Lake Marsh site.

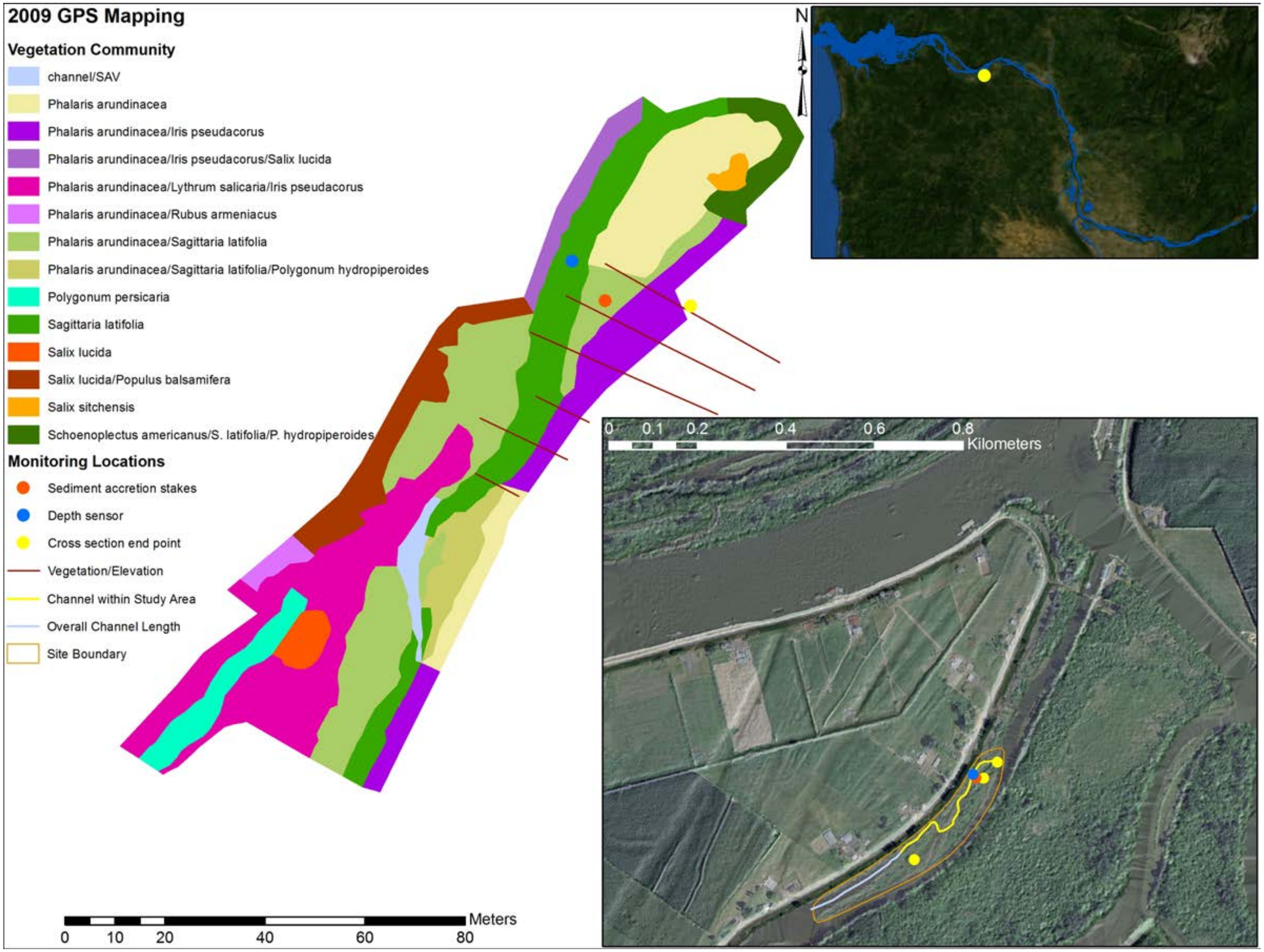


Figure A.8. Map showing the Clatskanie River Marsh site.

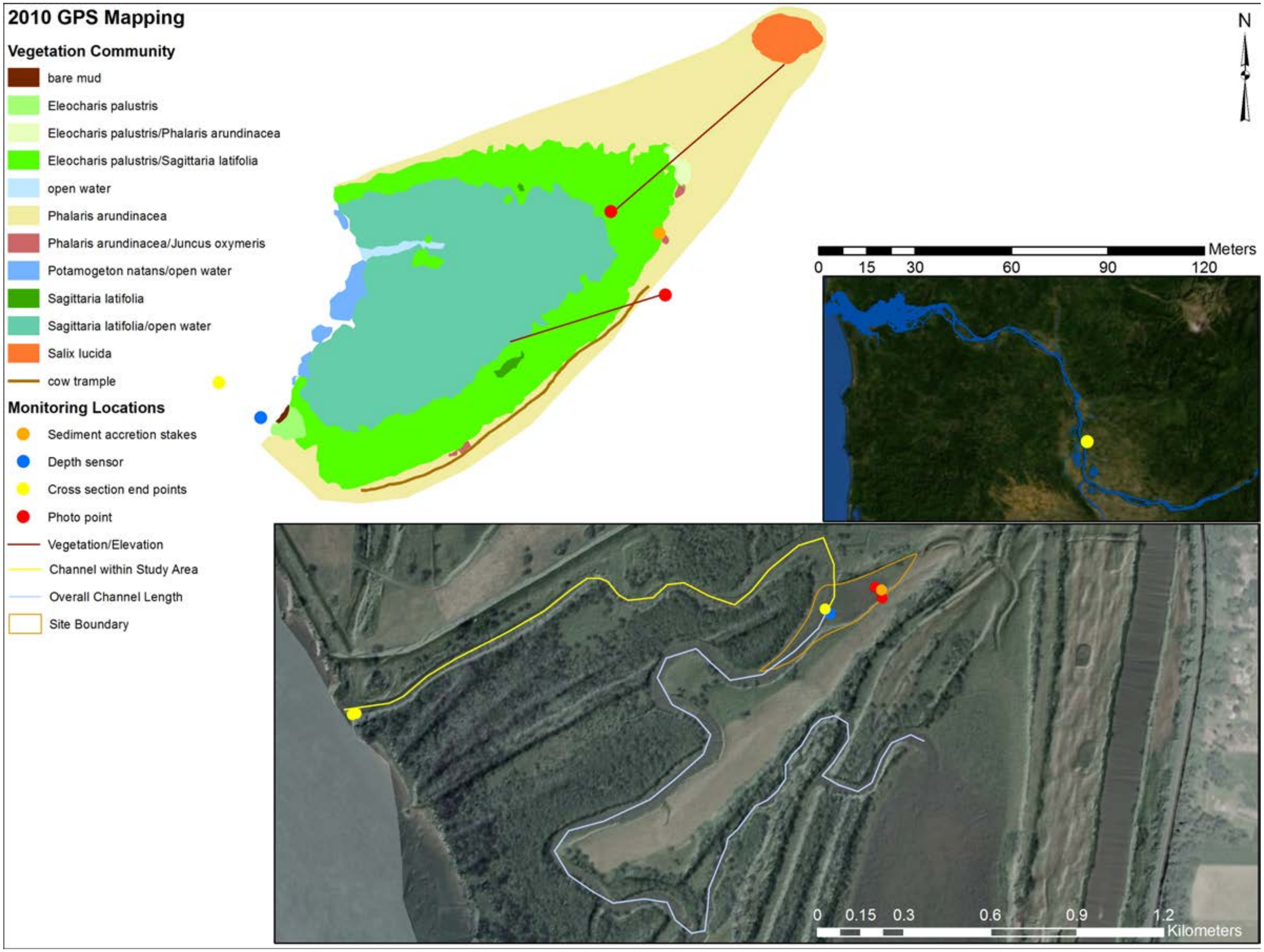


Figure A.9. Map showing the Campbell Slough Marsh site.

Figure A.10. Map showing the Cooperage Slough Marsh site.

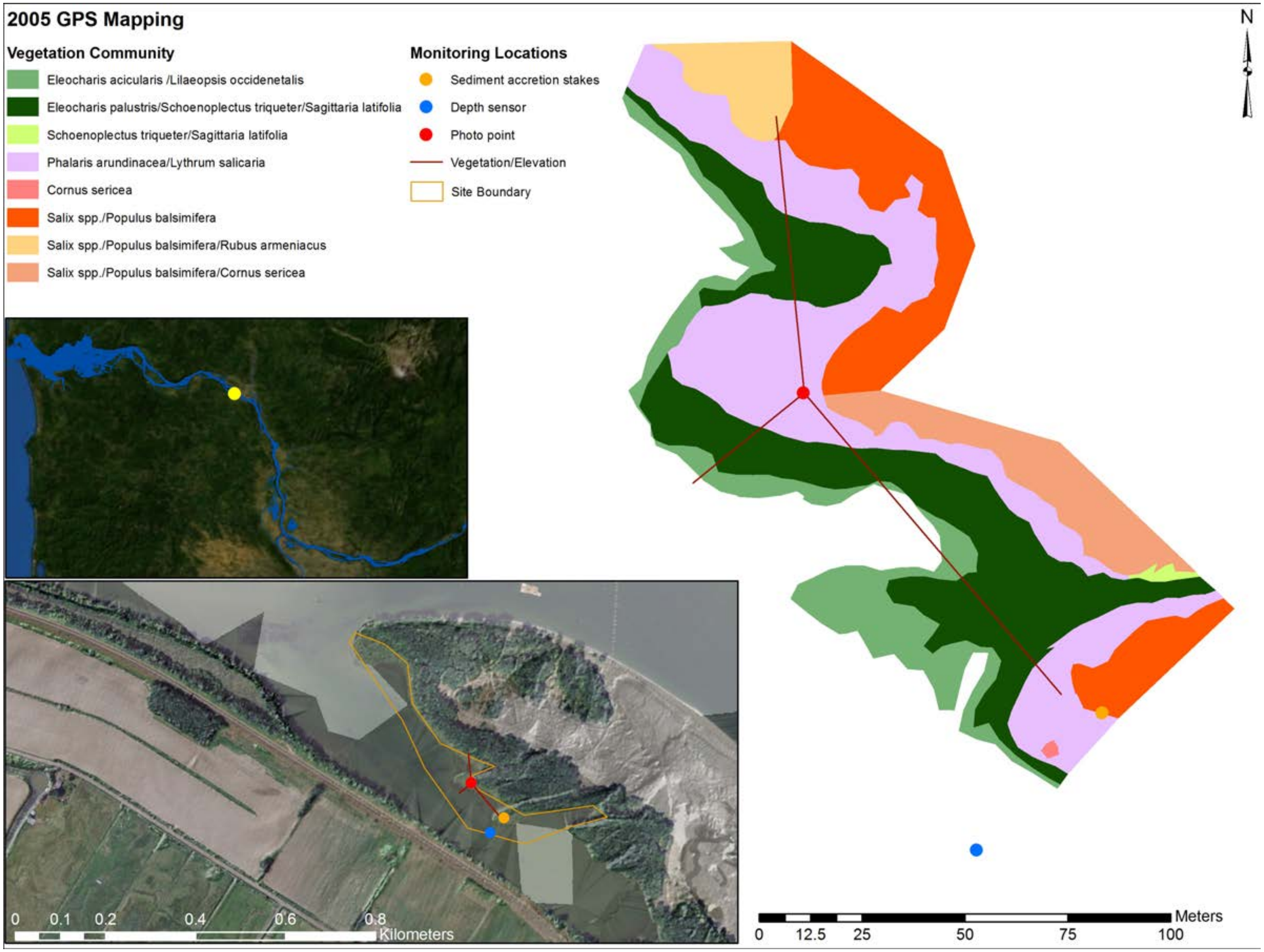


Figure A.11. Map showing the Dibblee Slough Marsh site.

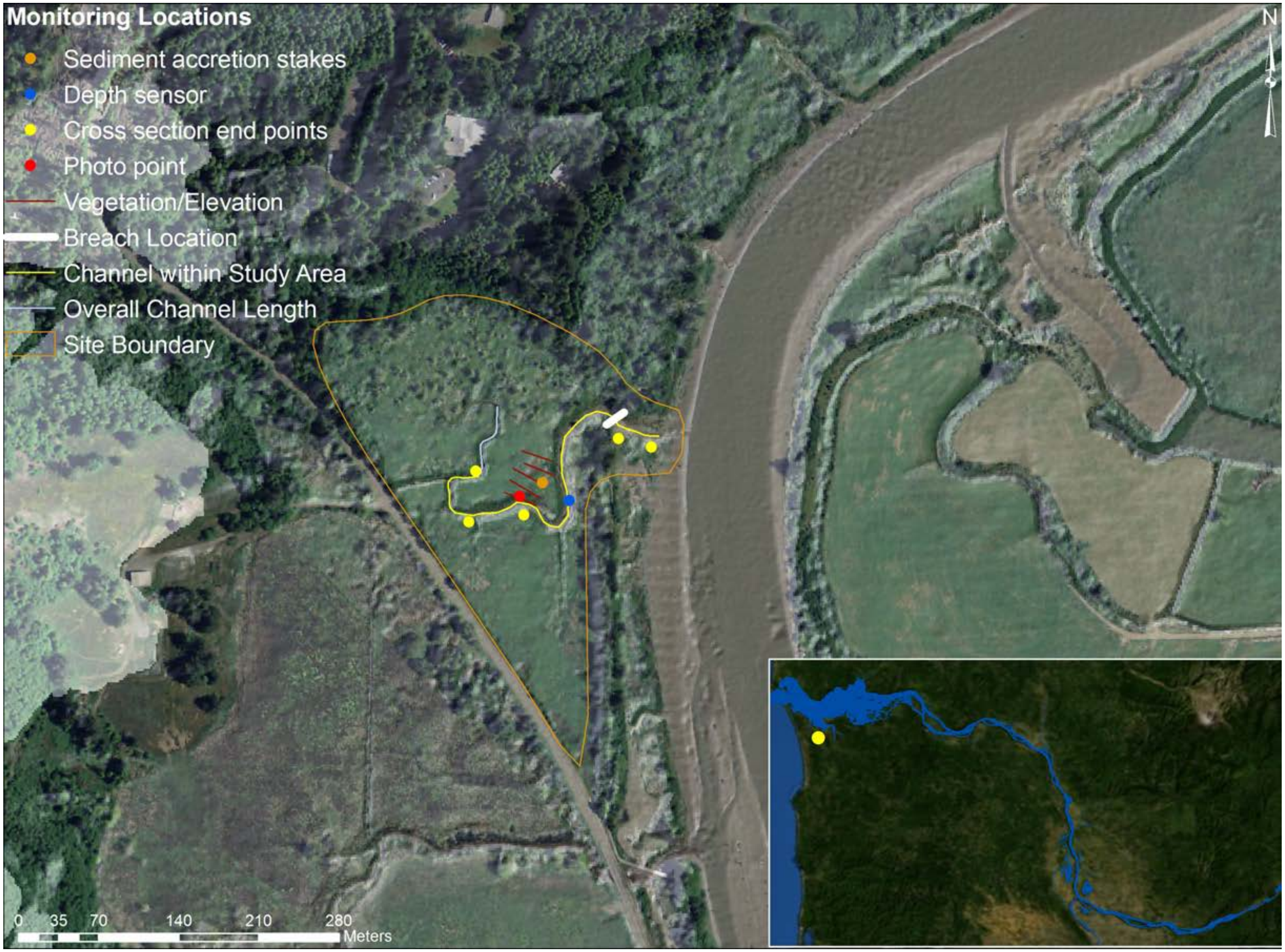


Figure A.12. Map showing the Ft. Clatsop Dike-breach Marsh site.

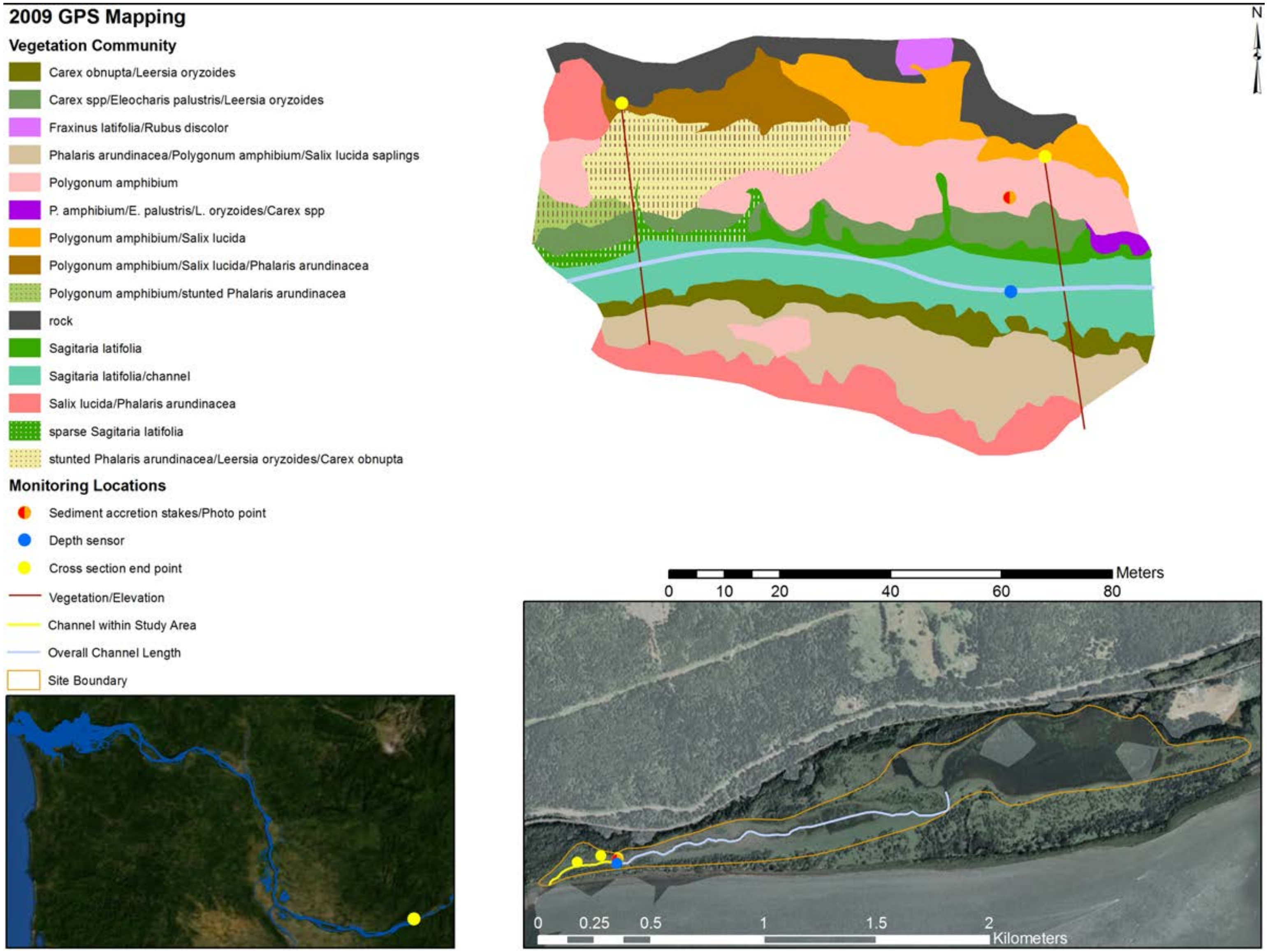


Figure A.13. Map showing the Franz Lake Marsh site.

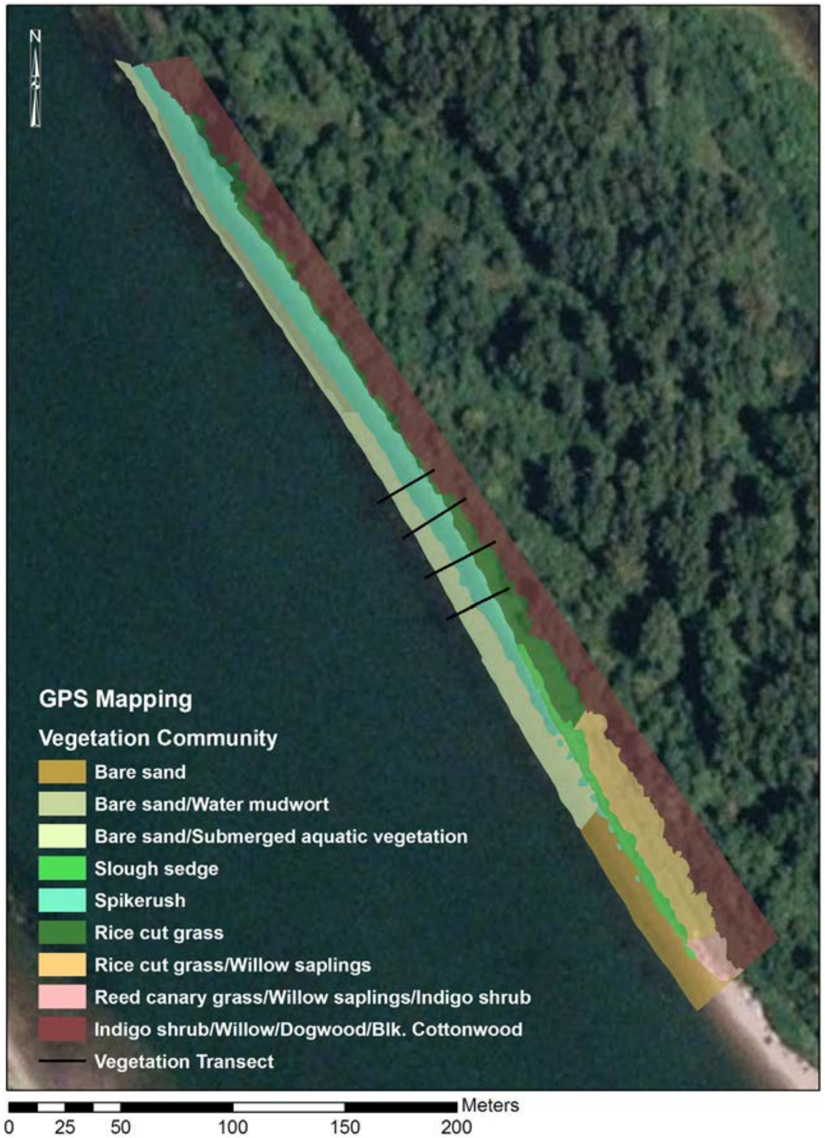


Figure A.14. Map showing the Gary Island Marsh site.

Figure A.15. Map showing the Gee Creek Riparian Wetland site.

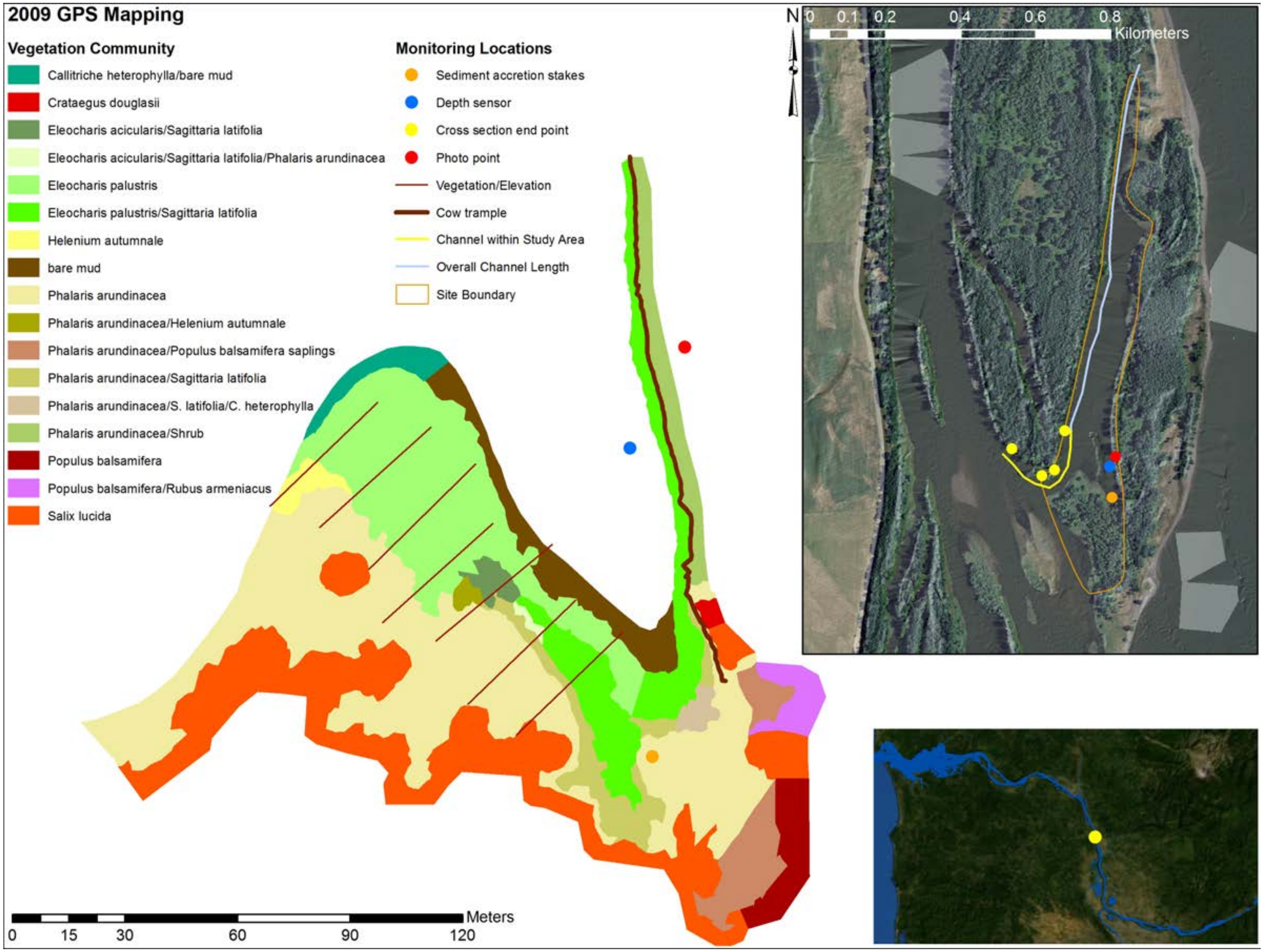


Figure A.16. Map showing the Goat Island Marsh site.

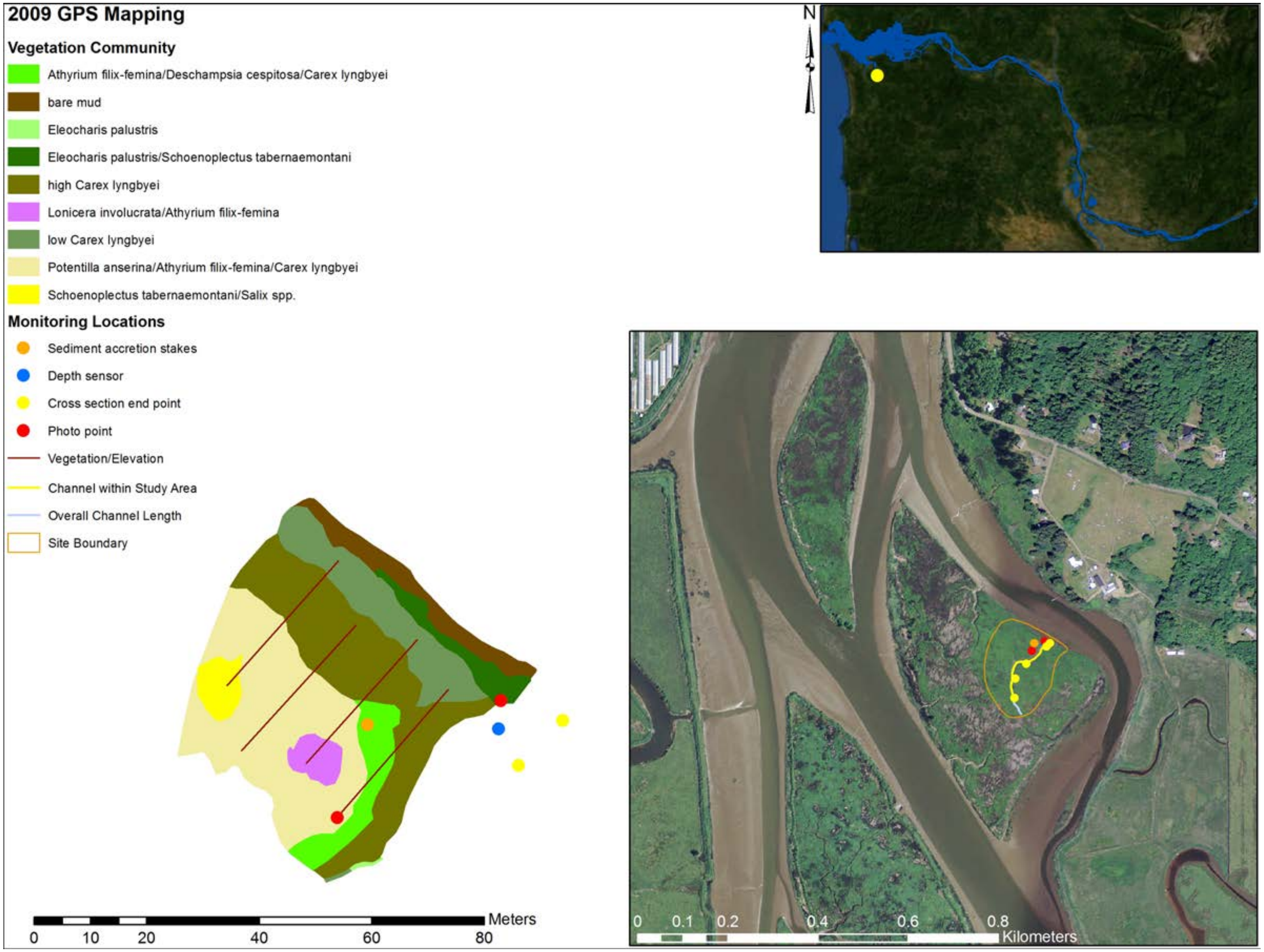


Figure A.17. Map showing the Grant Island Marsh site.

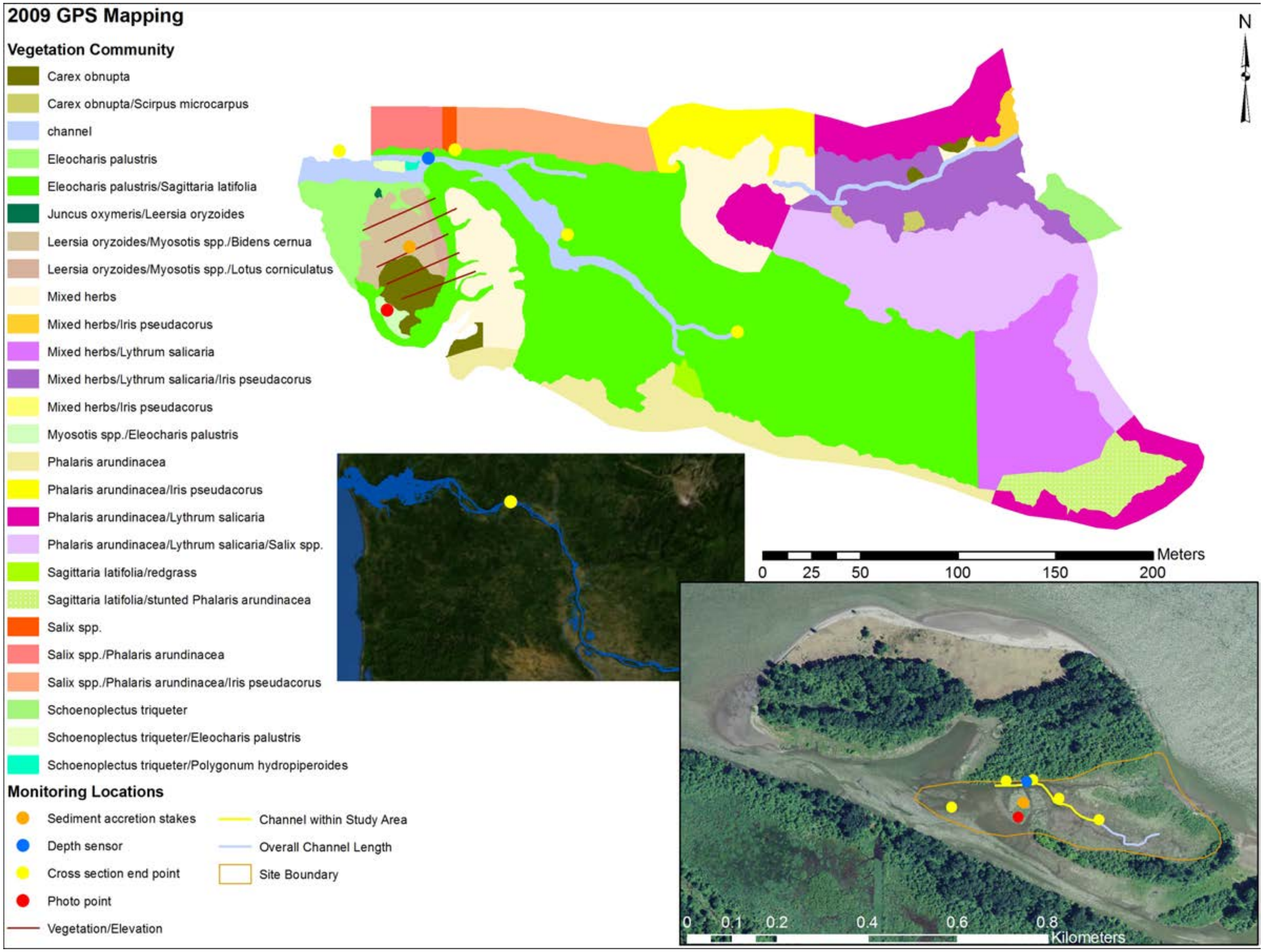


Figure A.18. Map showing the Gull Island Marsh site.

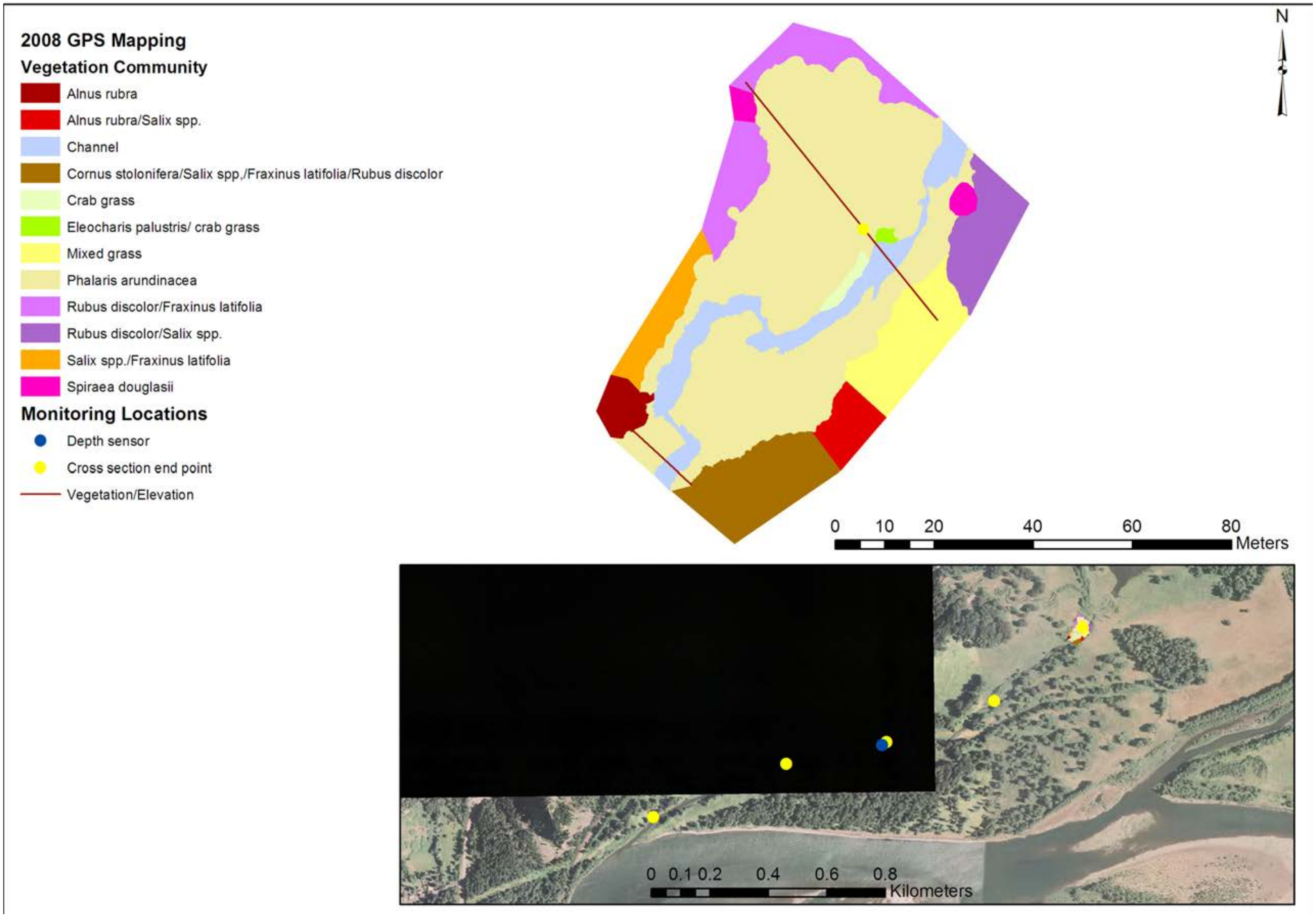


Figure A.19. Map showing the Hardy Creek Marsh site.

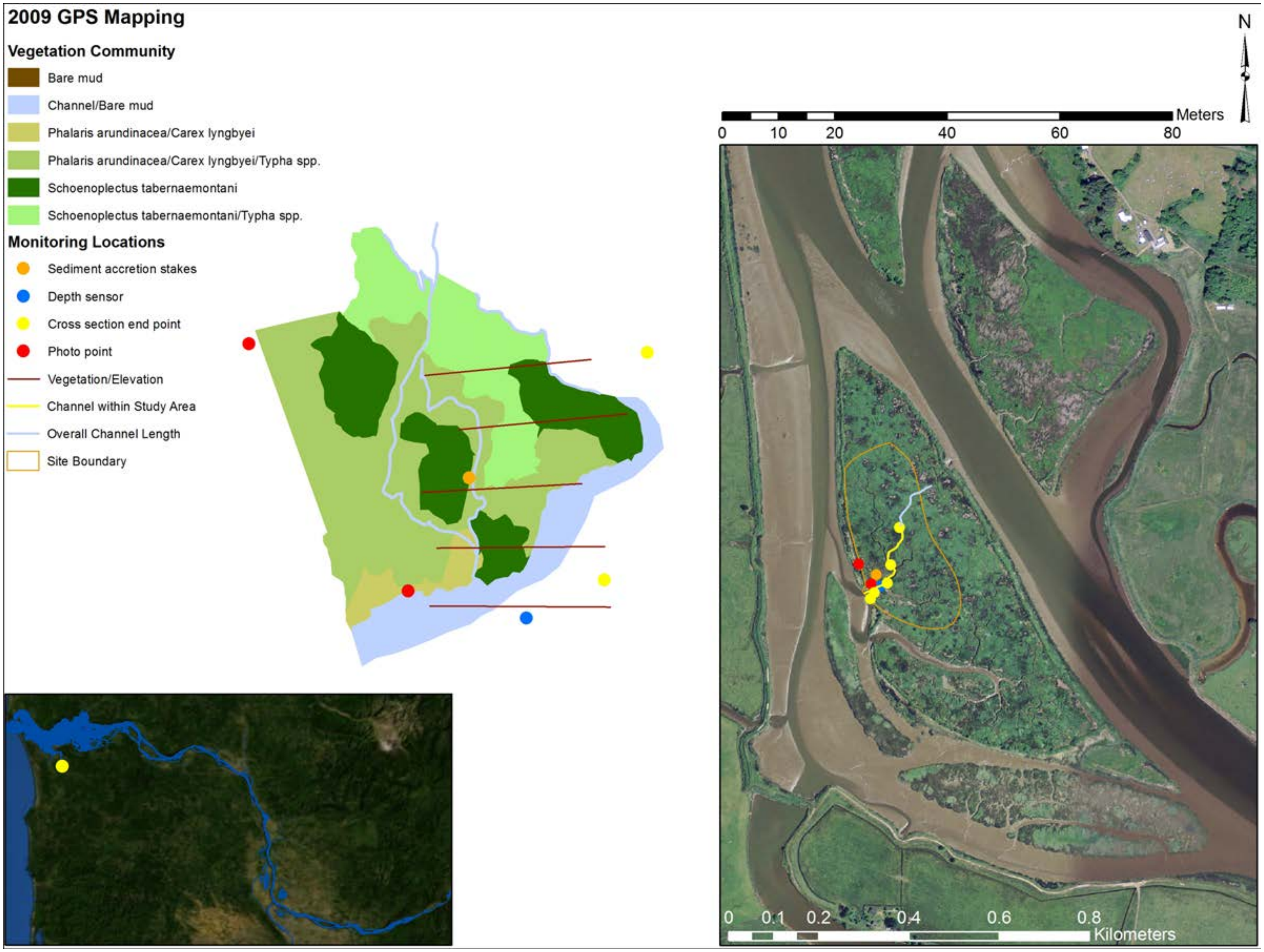


Figure A.20. Map showing the Haven Island Dike-breach Marsh site.

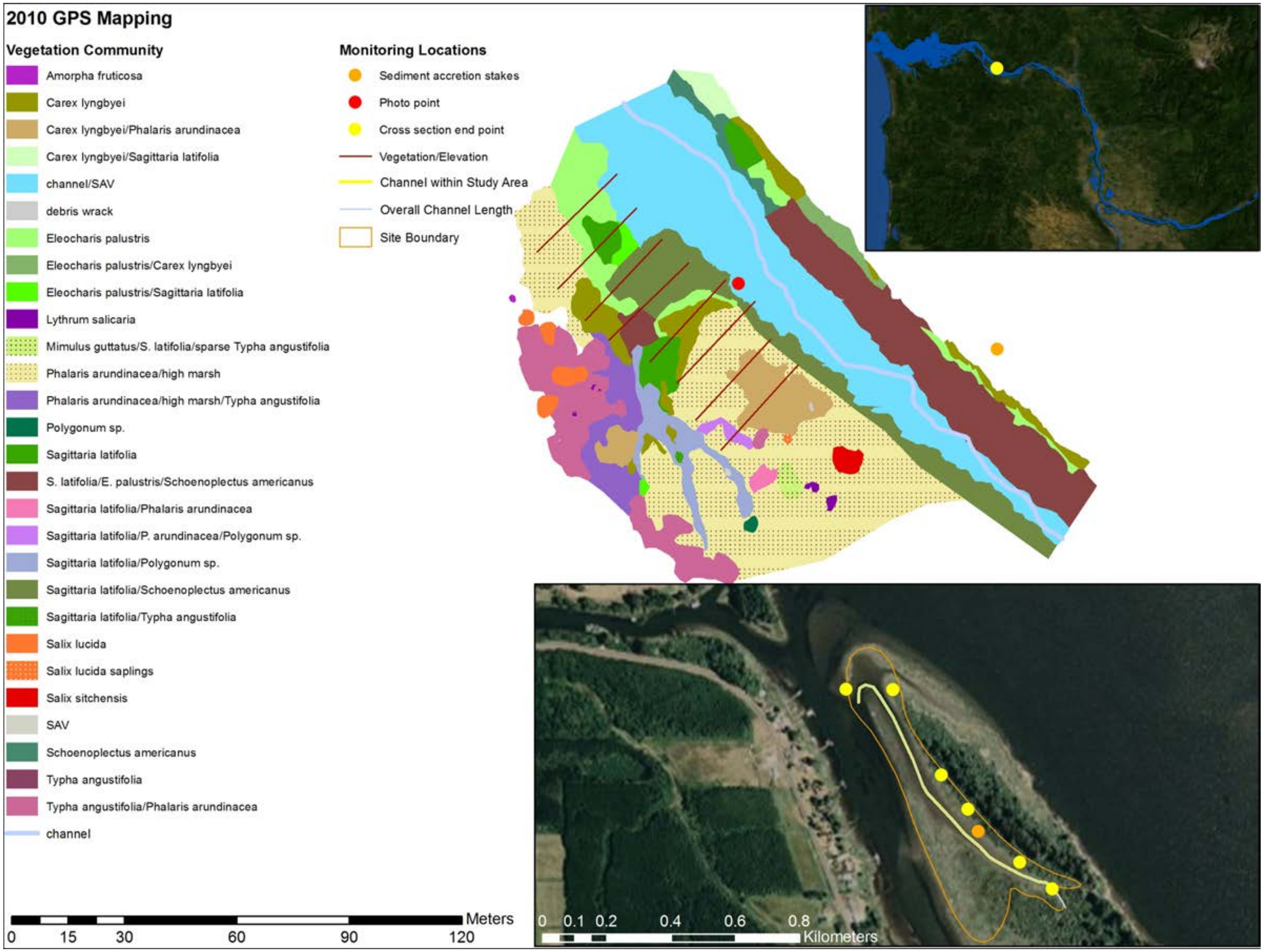


Figure A.21. Map showing the Jackson Island Marsh site.

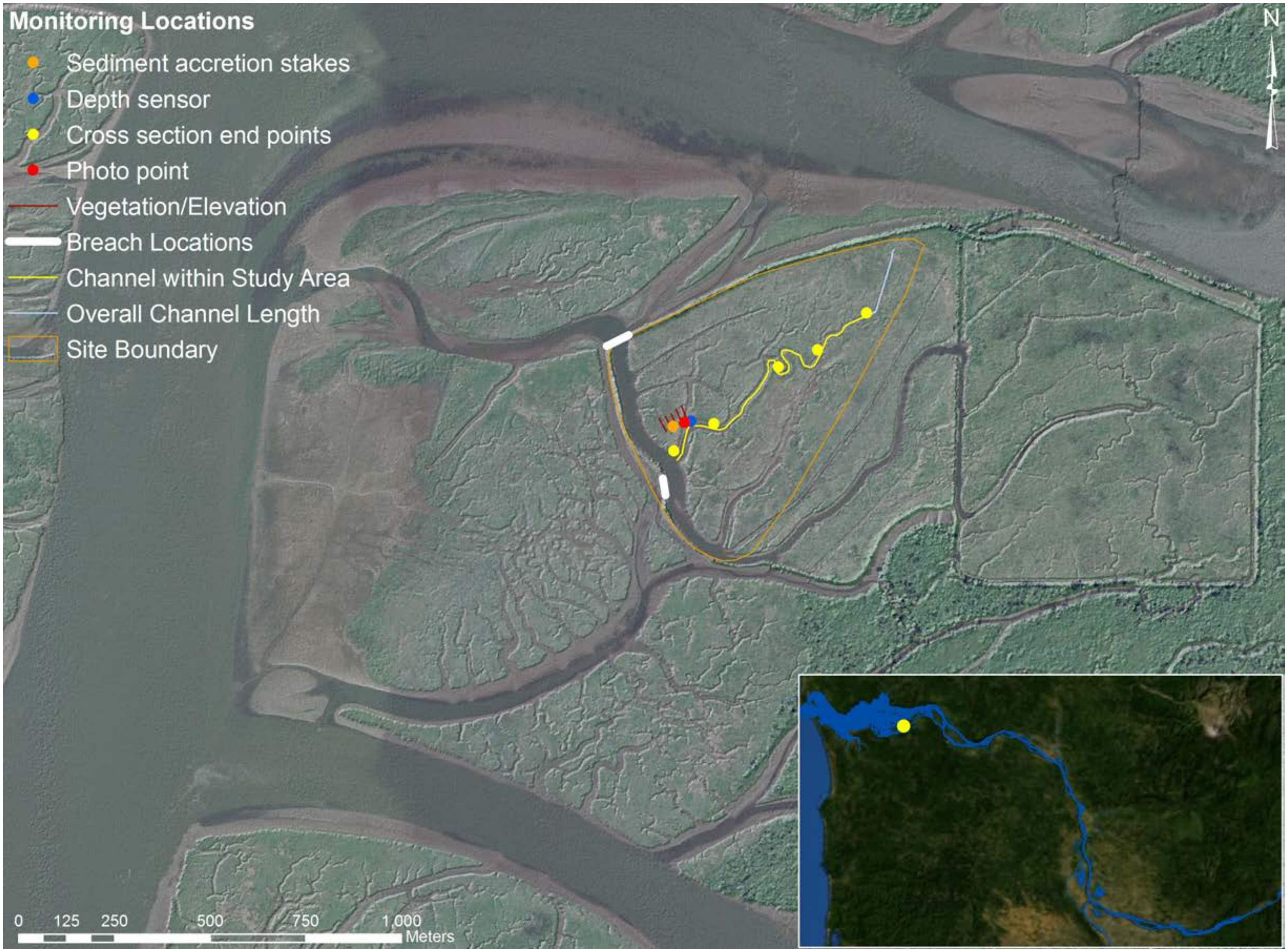


Figure A.22. Map showing the Karlson Island Dike-breach Marsh site.

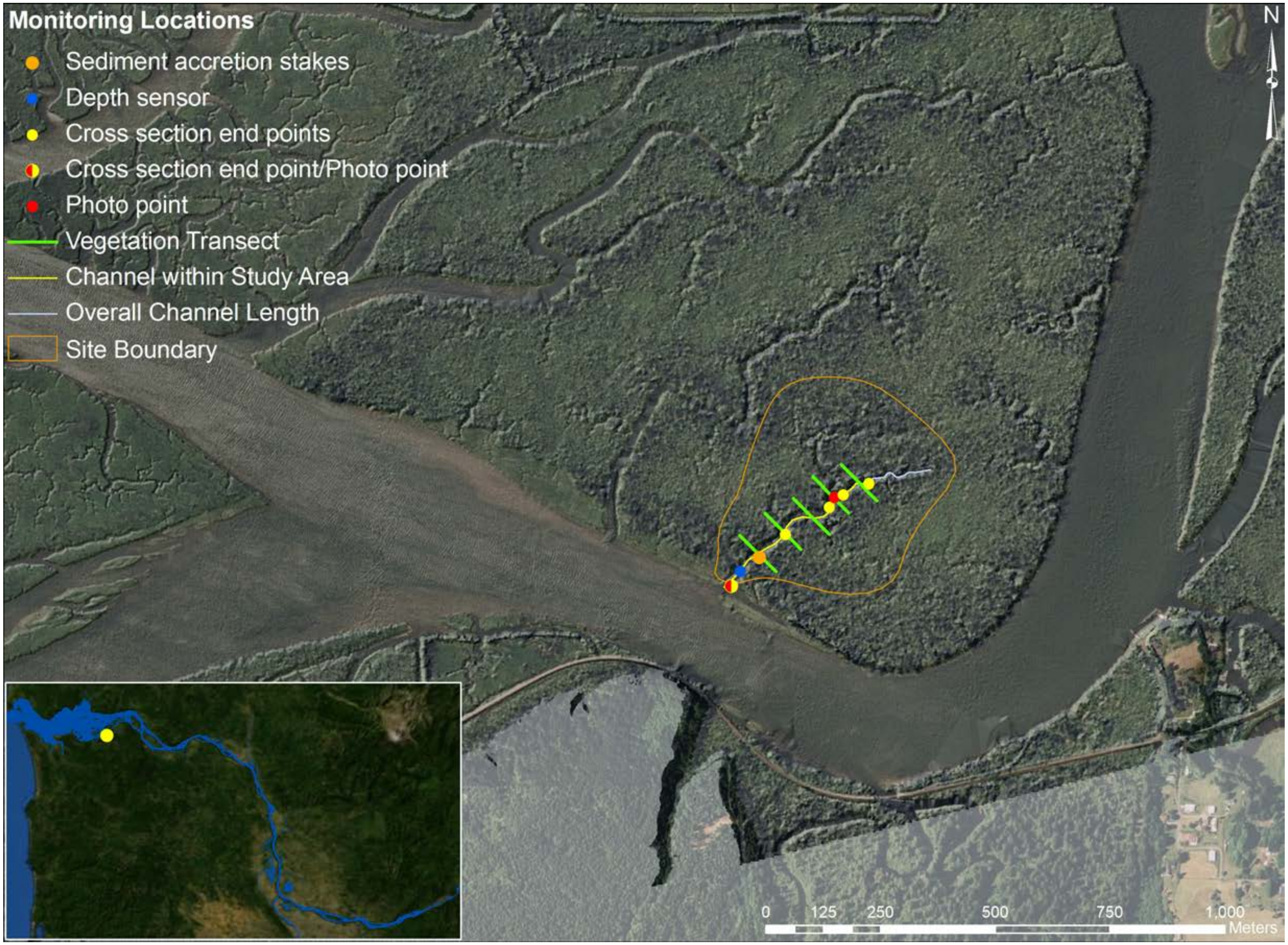


Figure A.23. Map showing the Karlson Island Swamp site.

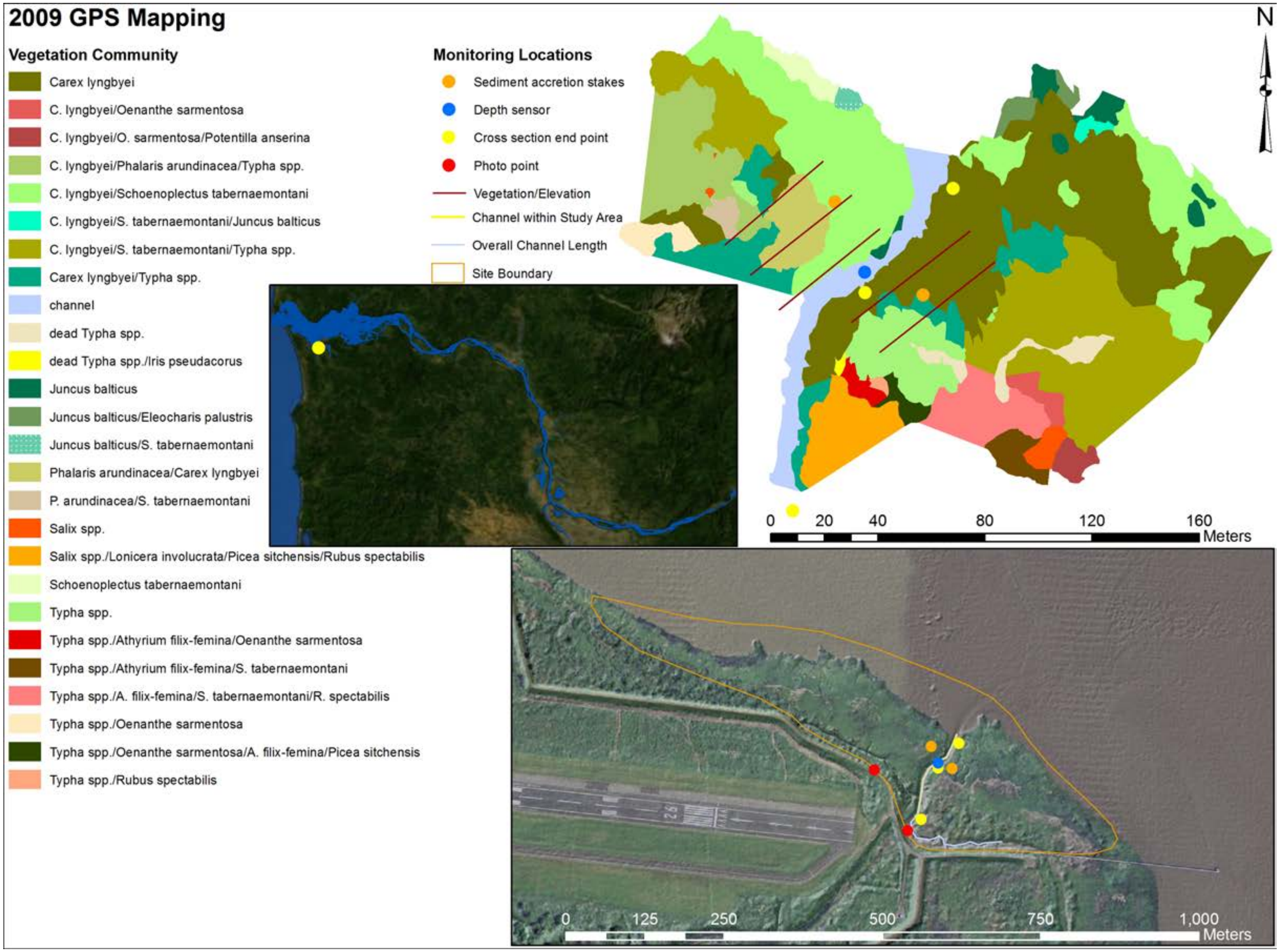


Figure A.24. Map showing the Lewis & Clark River (mouth) Marsh site.

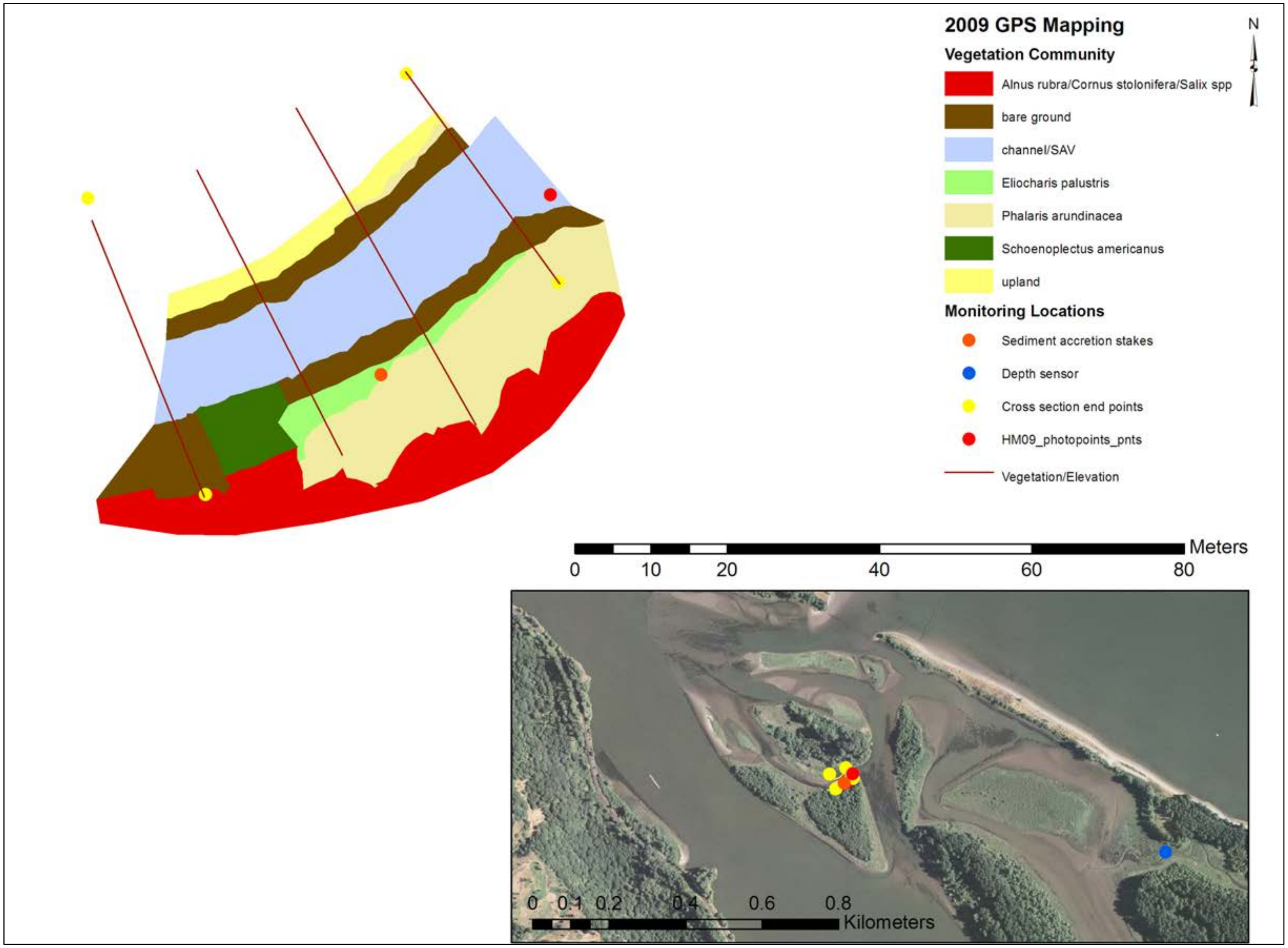


Figure A.25. Map showing the Lord Island 1 Marsh site.

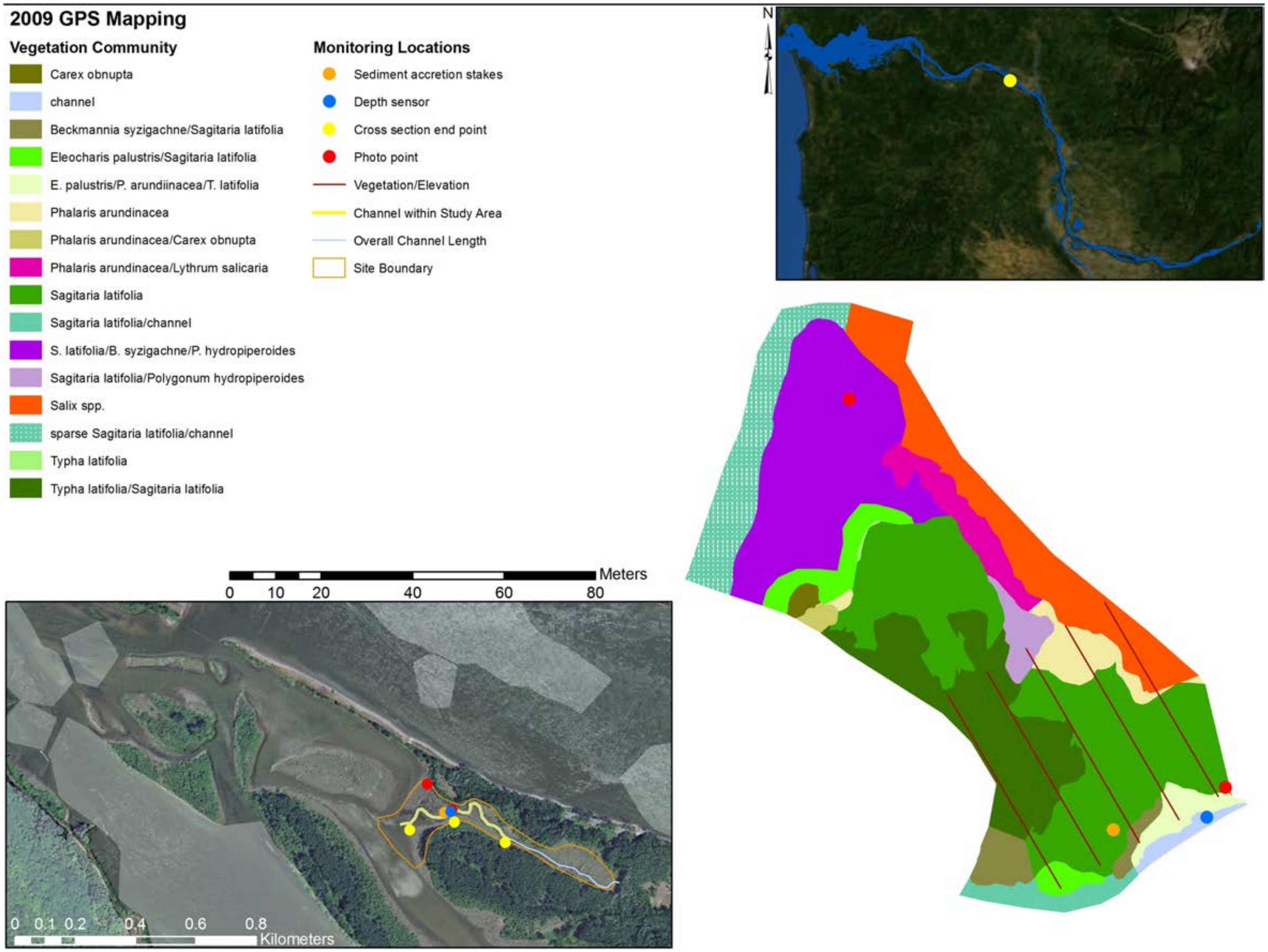


Figure A.26. Map showing the Lord Island 2 Marsh site.

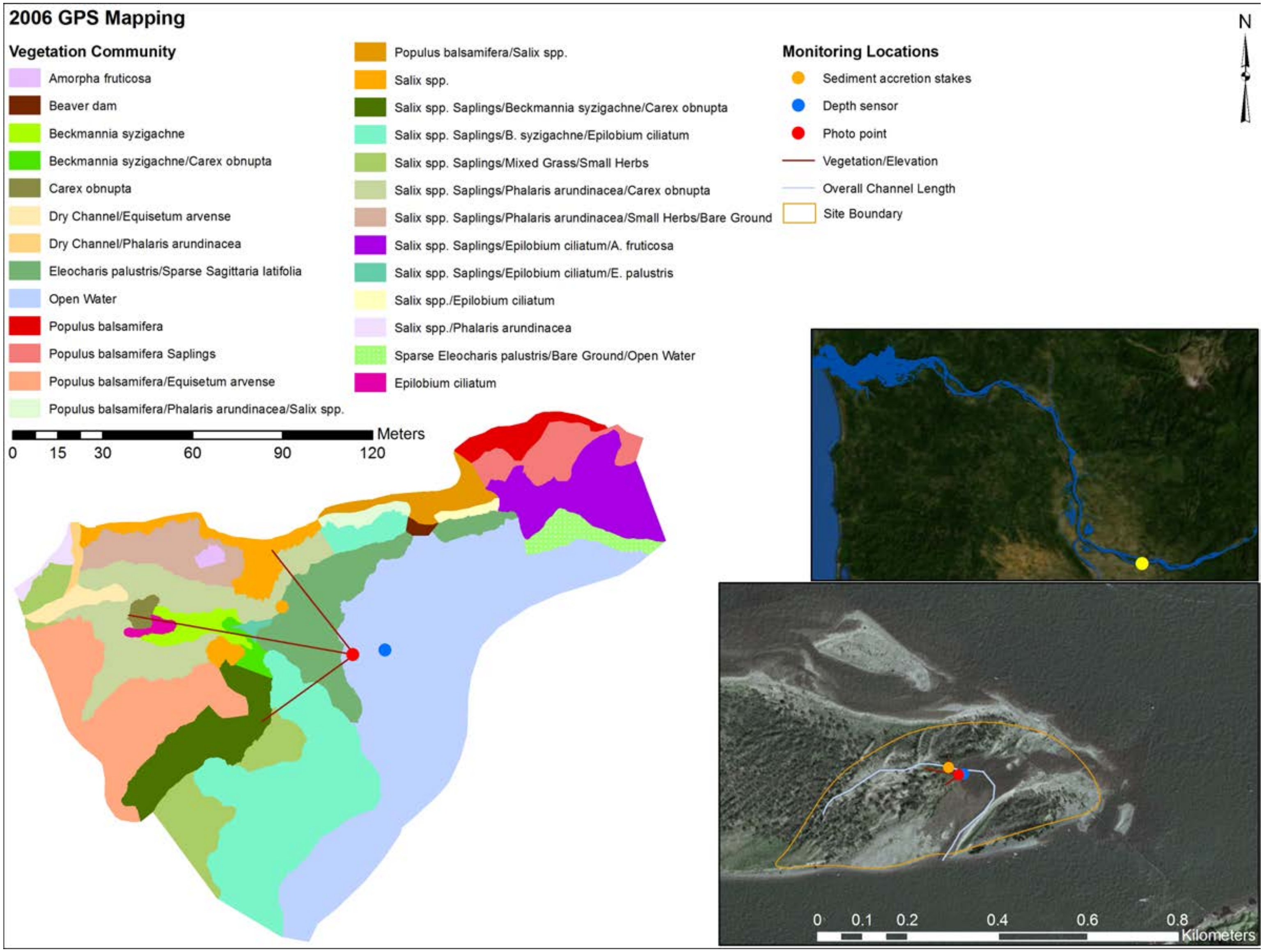


Figure A.27. Map showing the McGuire Island Marsh site.

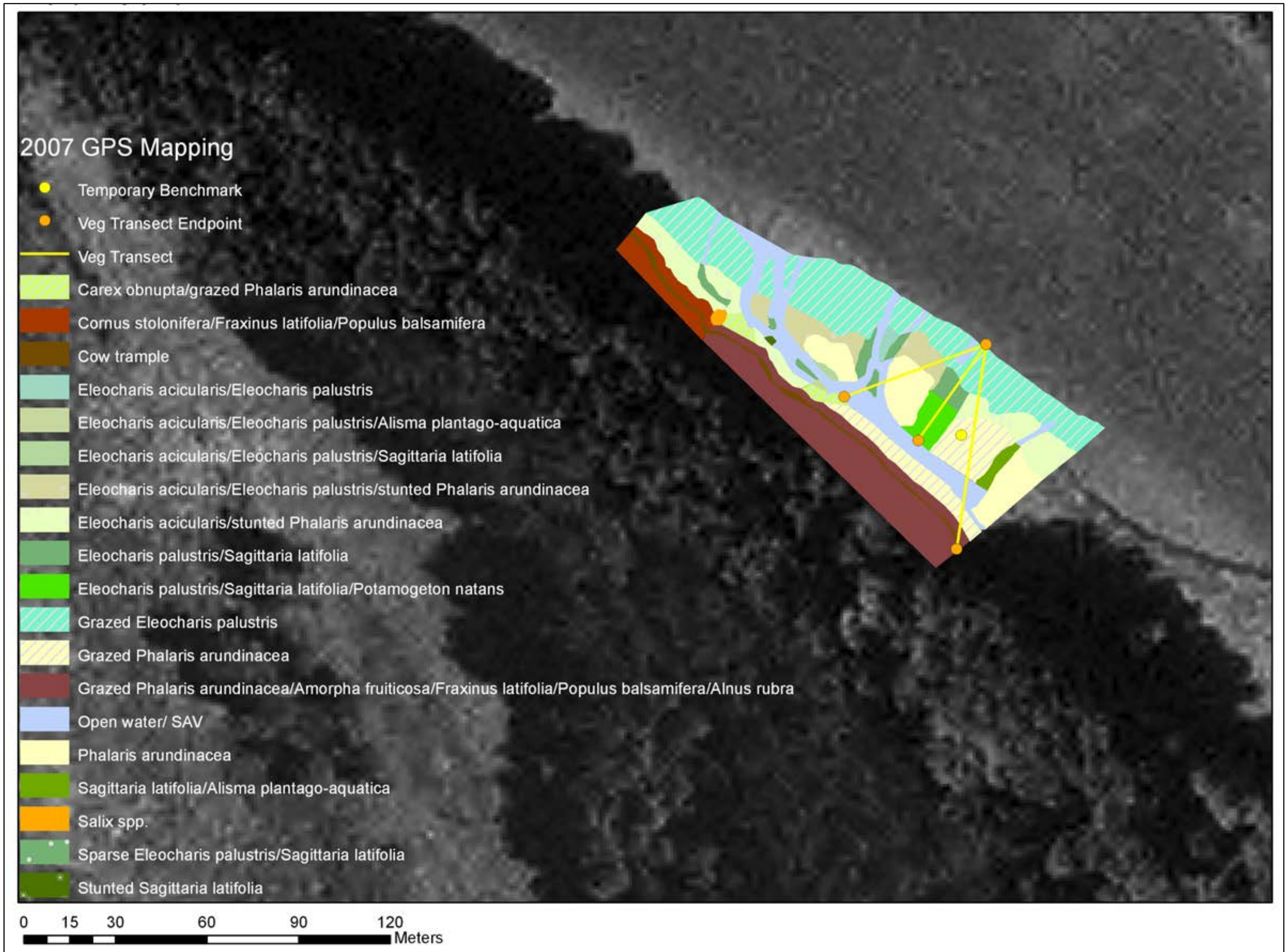


Figure A.28. Map showing the Martin Island Marsh site.

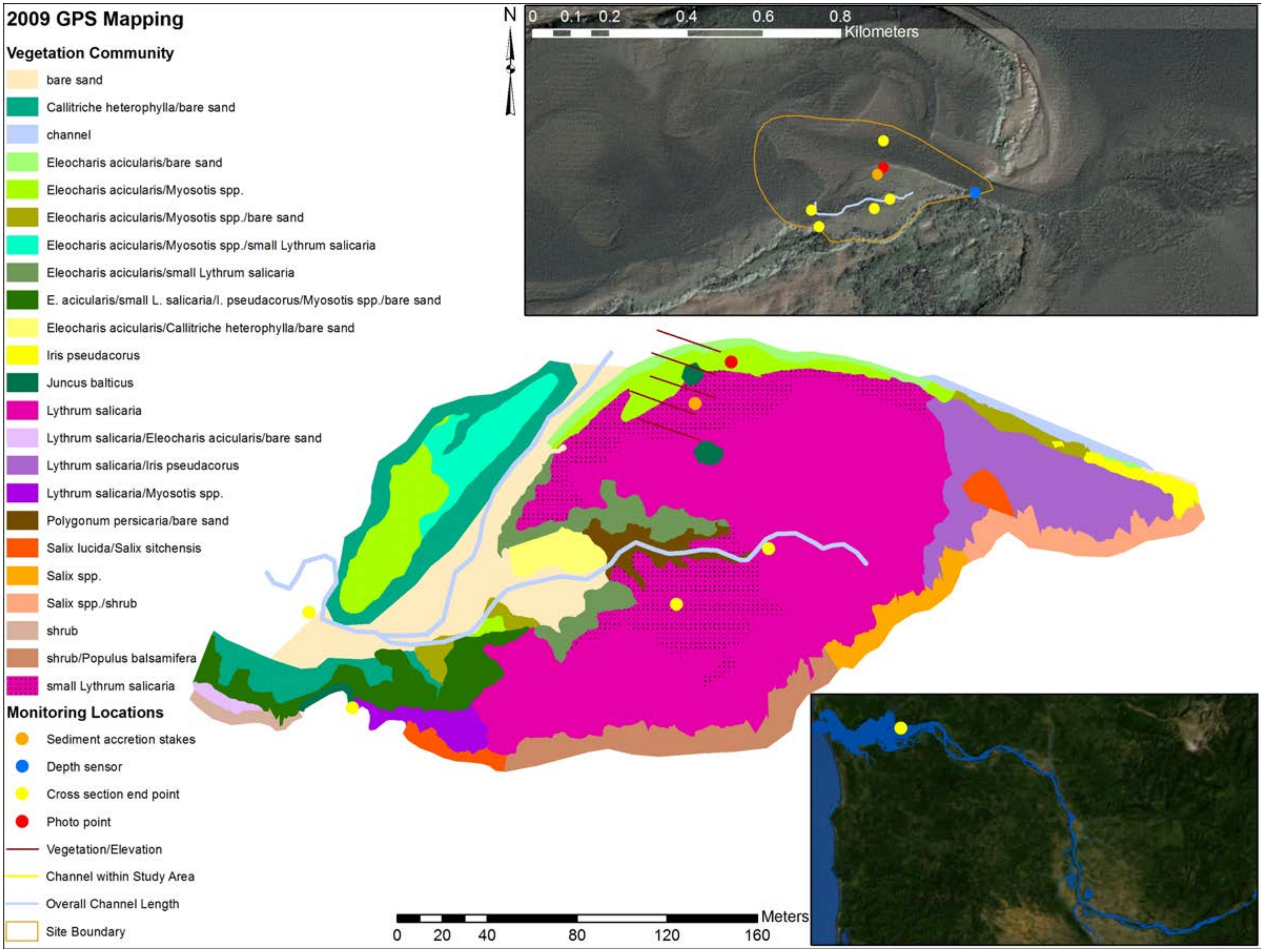


Figure A.29. Map showing the Miller Sands Marsh site.

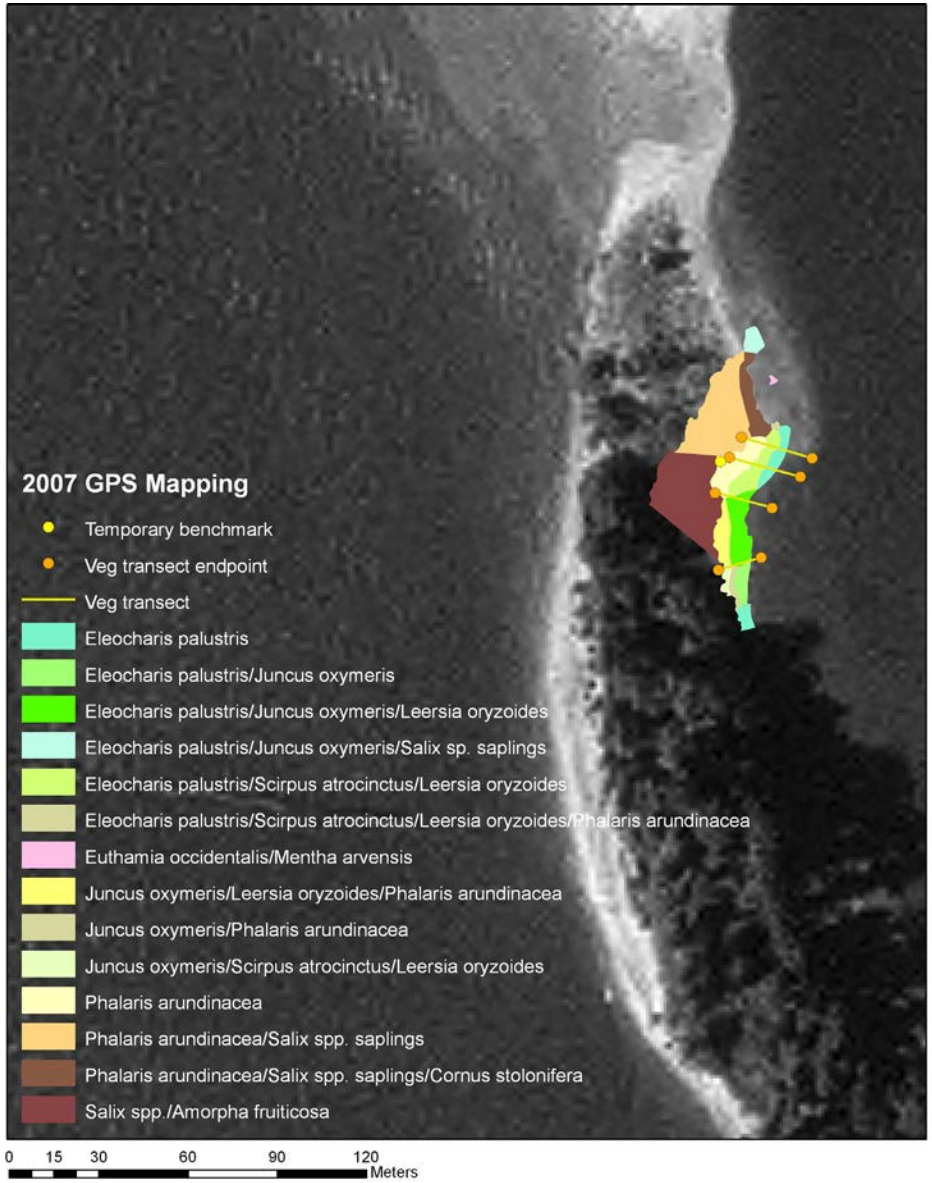


Figure A.30. Map showing the No-Name Island Marsh site.

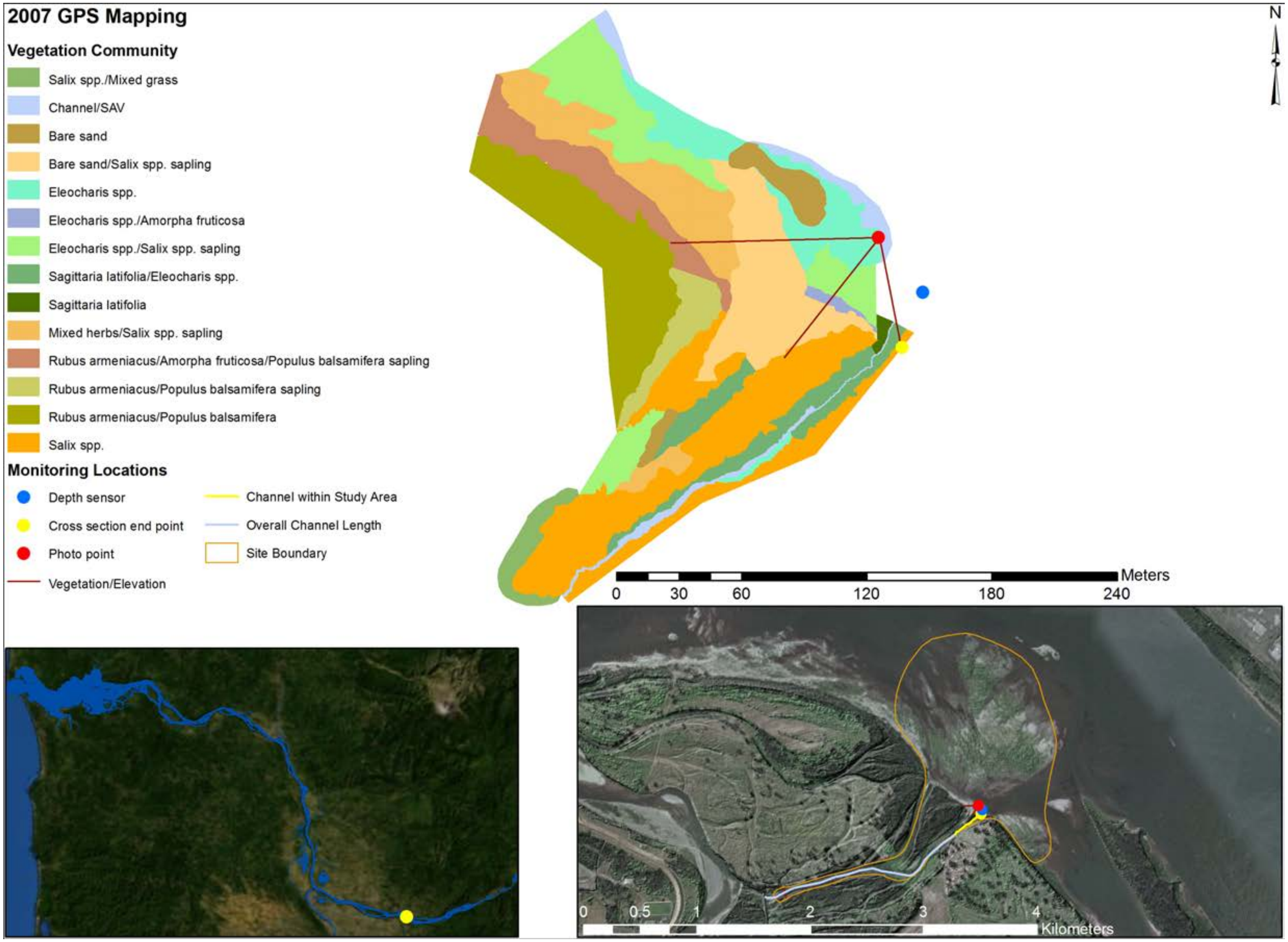


Figure A.31. Map showing the Sandy River Delta (old channel mouth) Marsh site.

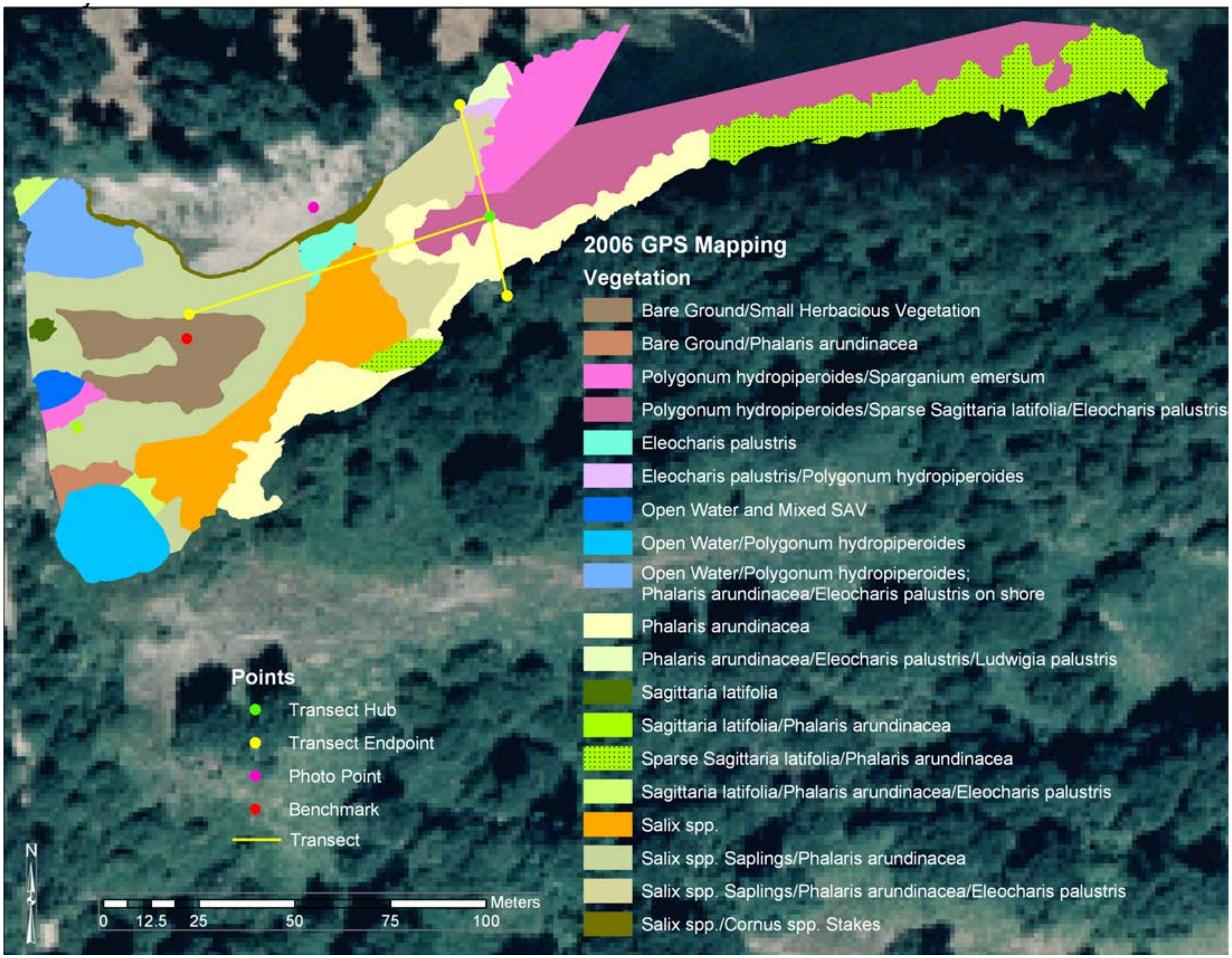


Figure A.32. Map showing the Old Sandy River Channel Marsh site.

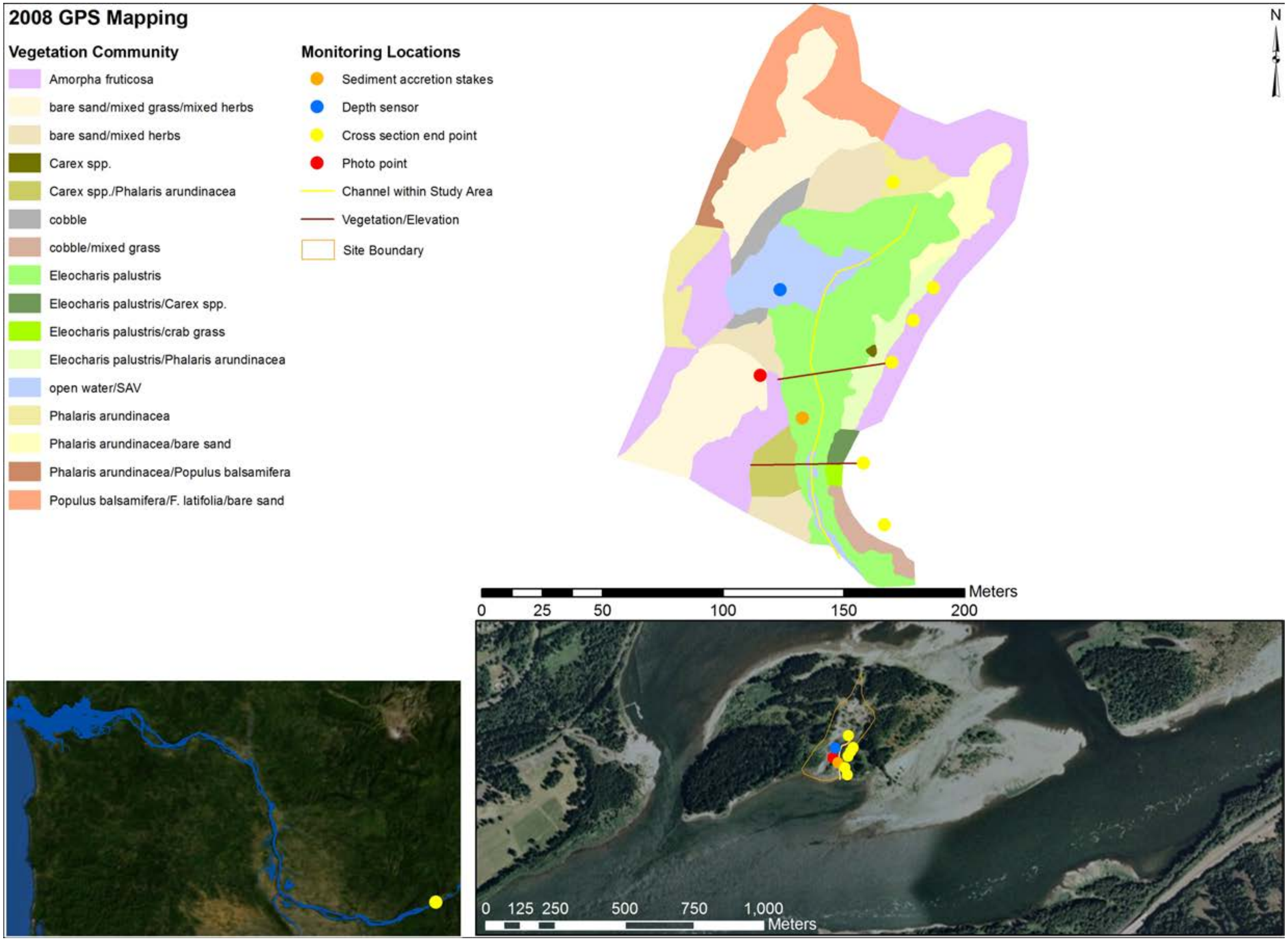


Figure A.33. Map showing the Pierce Island Marsh site.

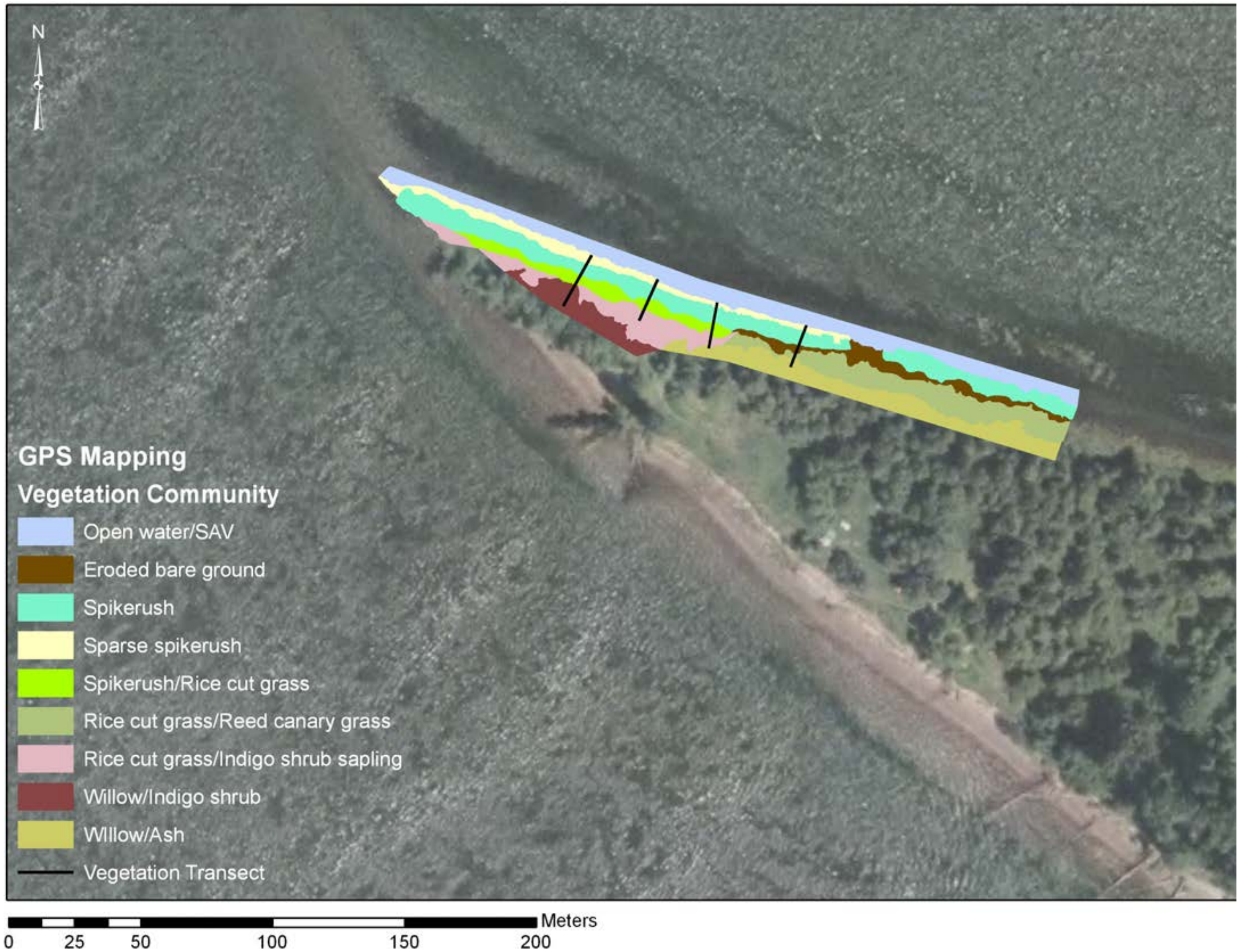


Figure A.34. Map showing the Reed Island Marsh site.

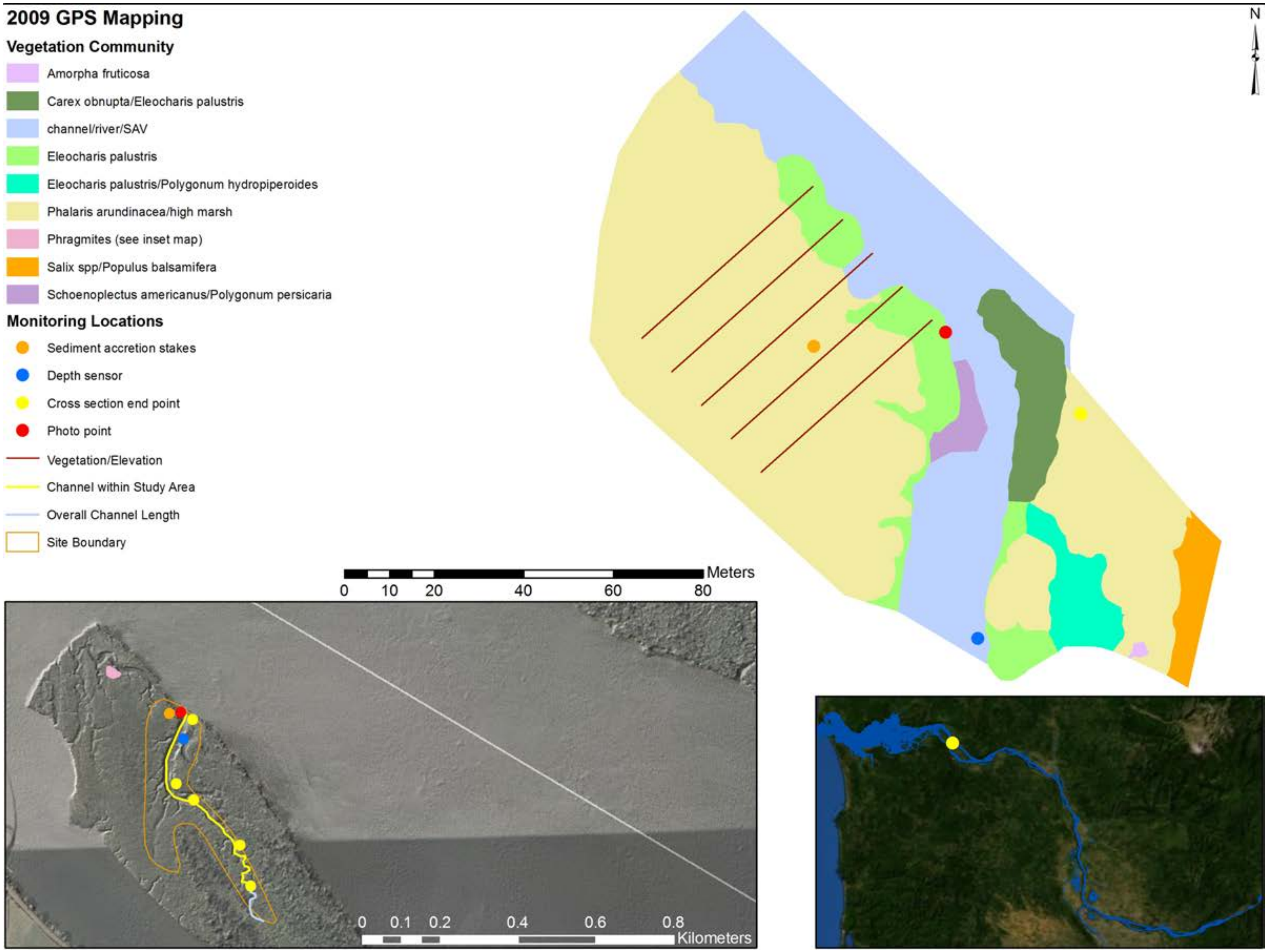


Figure A.35. Map showing the Ryan Island Marsh site.

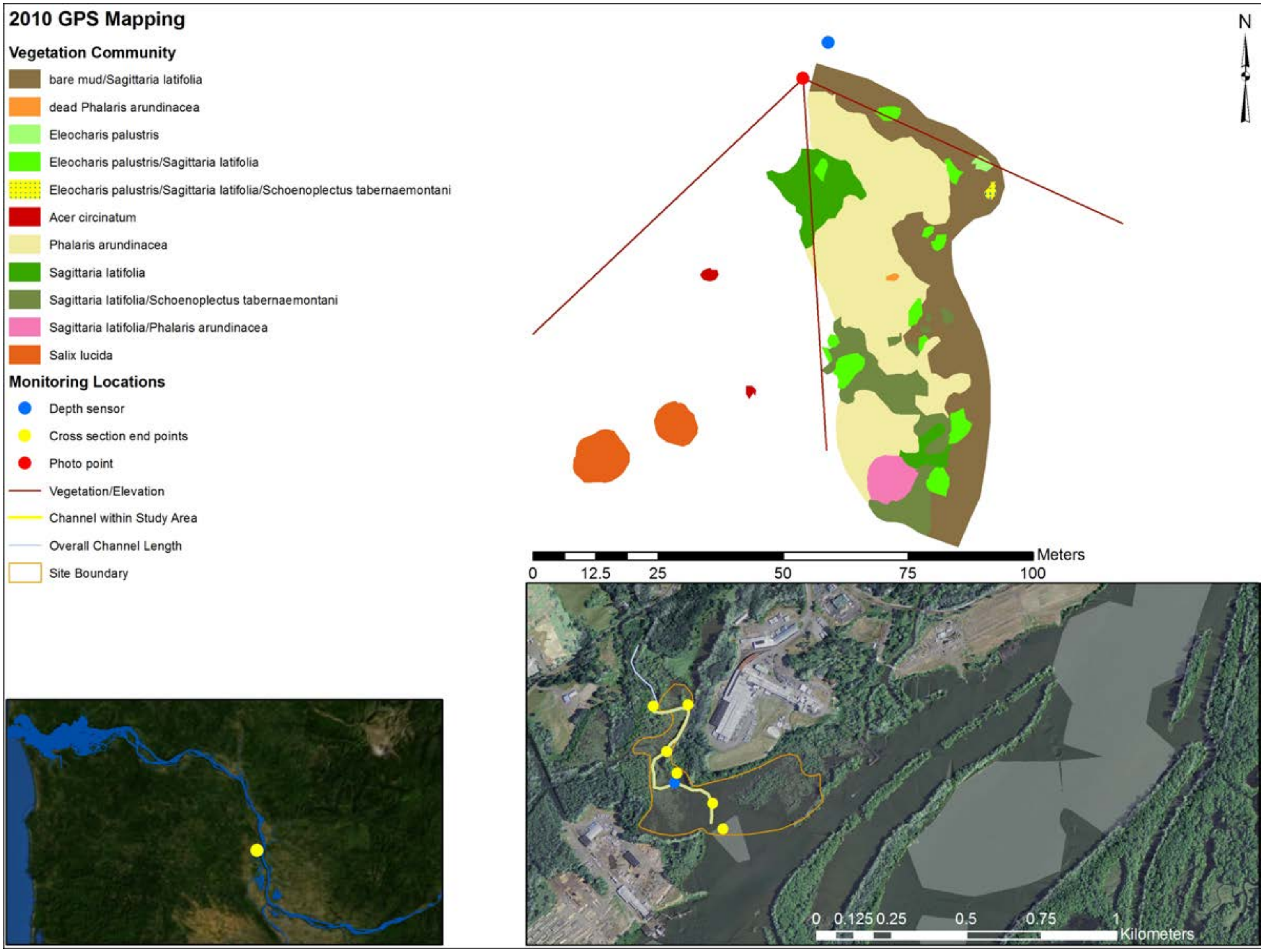


Figure A.36. Map showing the Scappoose Bay Marsh site.

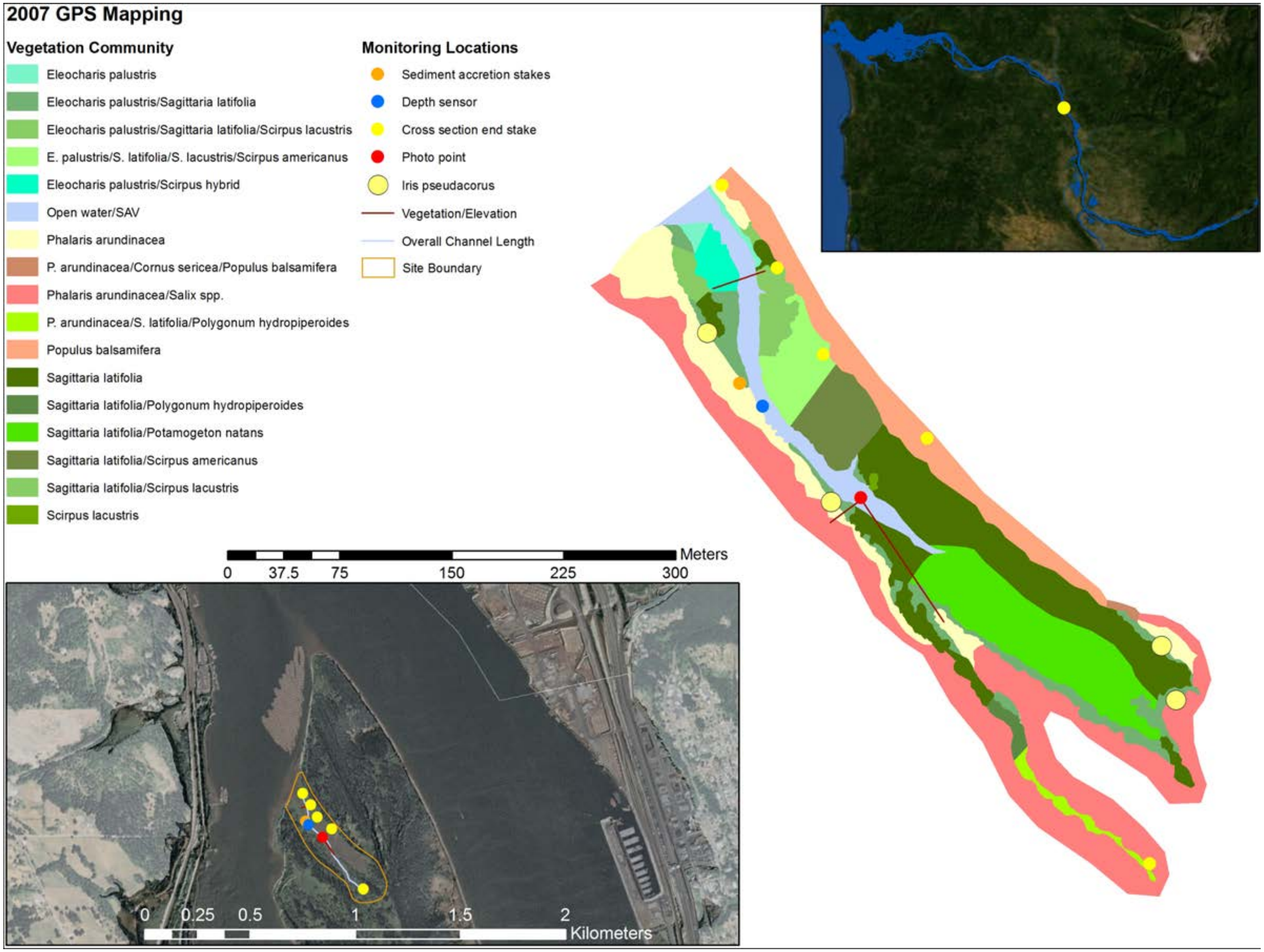


Figure A.37. Map showing the Sandy Island Slough Marsh site.

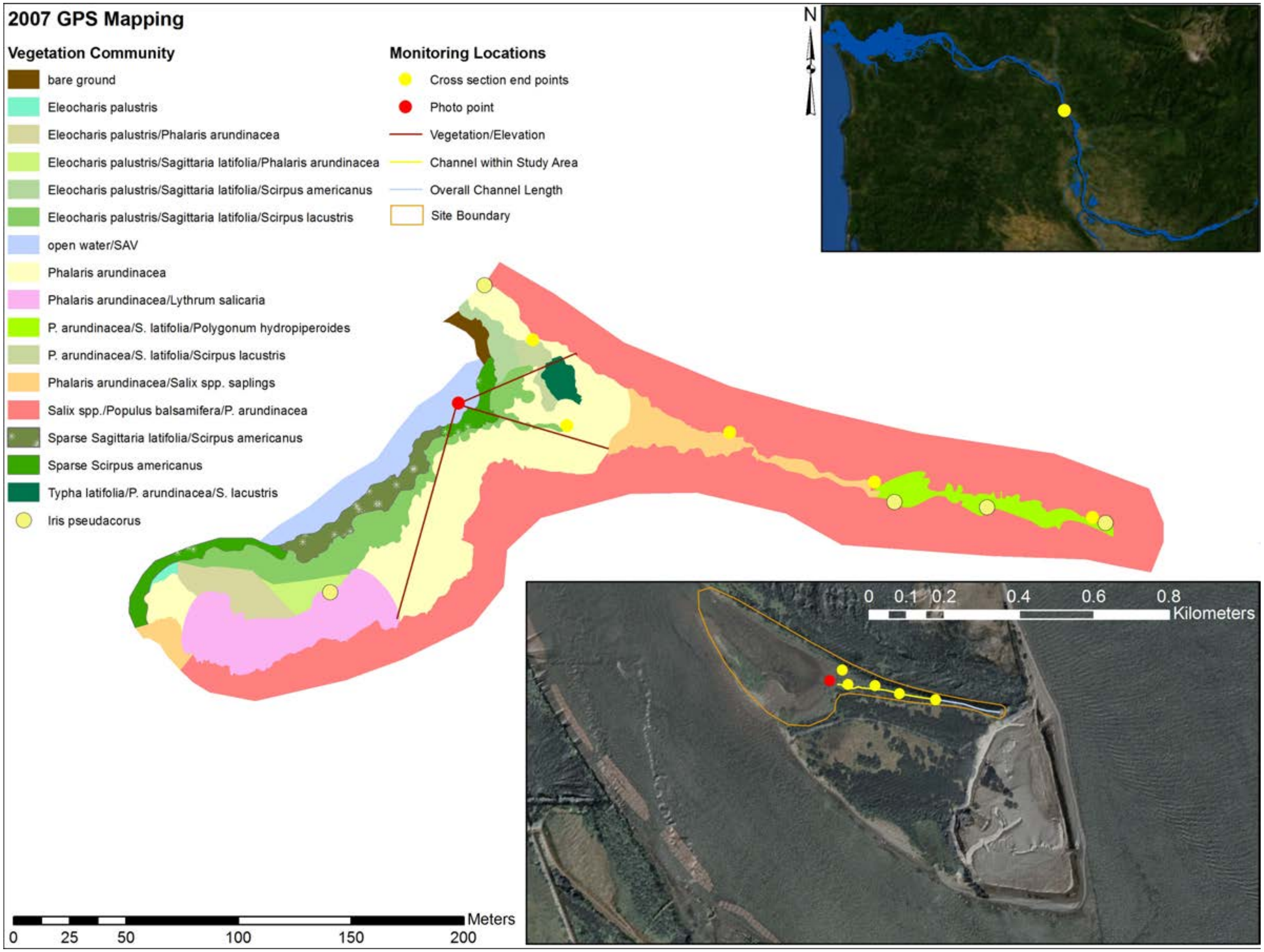


Figure A.38. Map showing the Sandy Island 2 Marsh site.

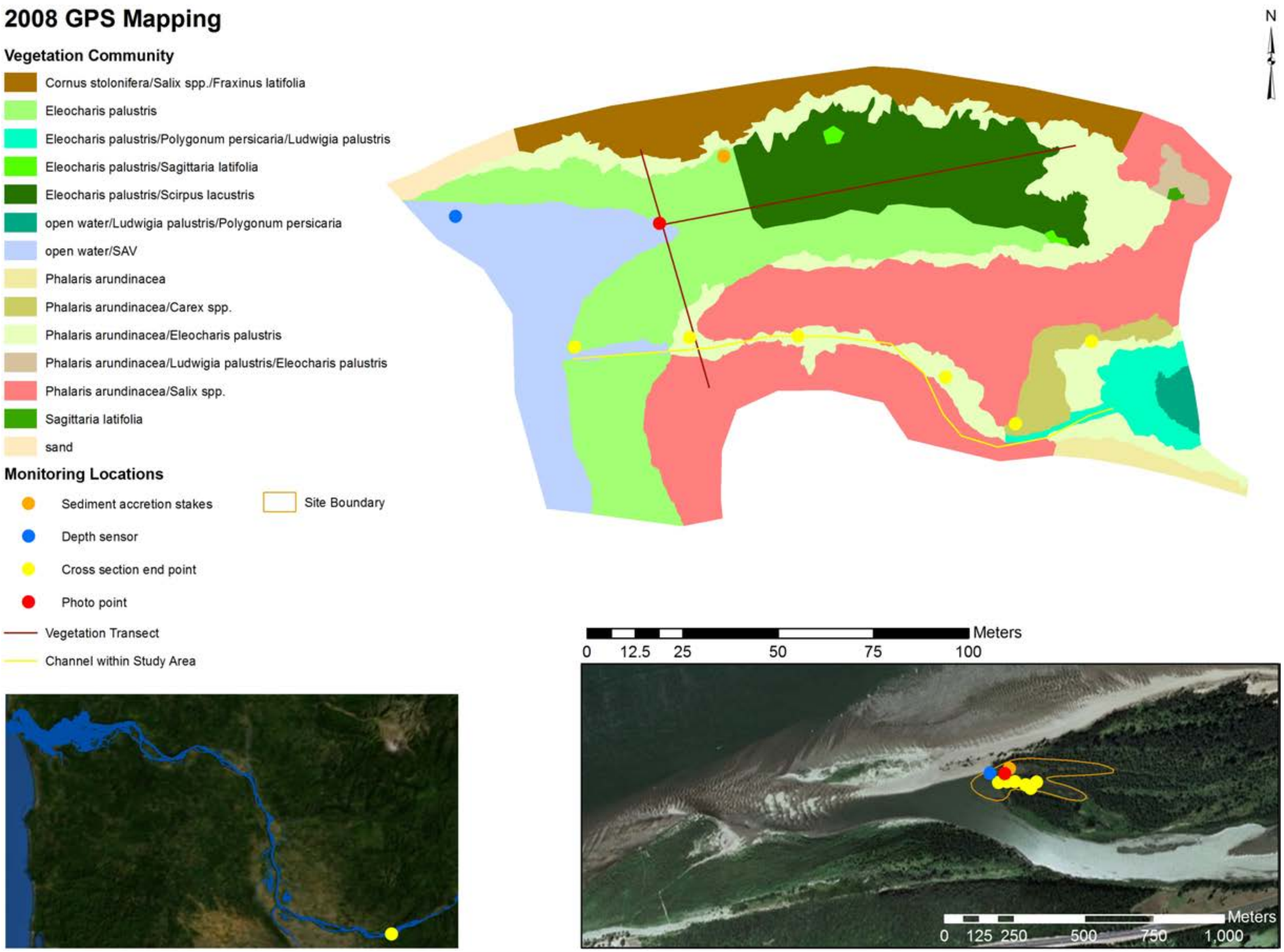


Figure A.39. Map showing the Sand Island (Rooster Rock) Marsh site.

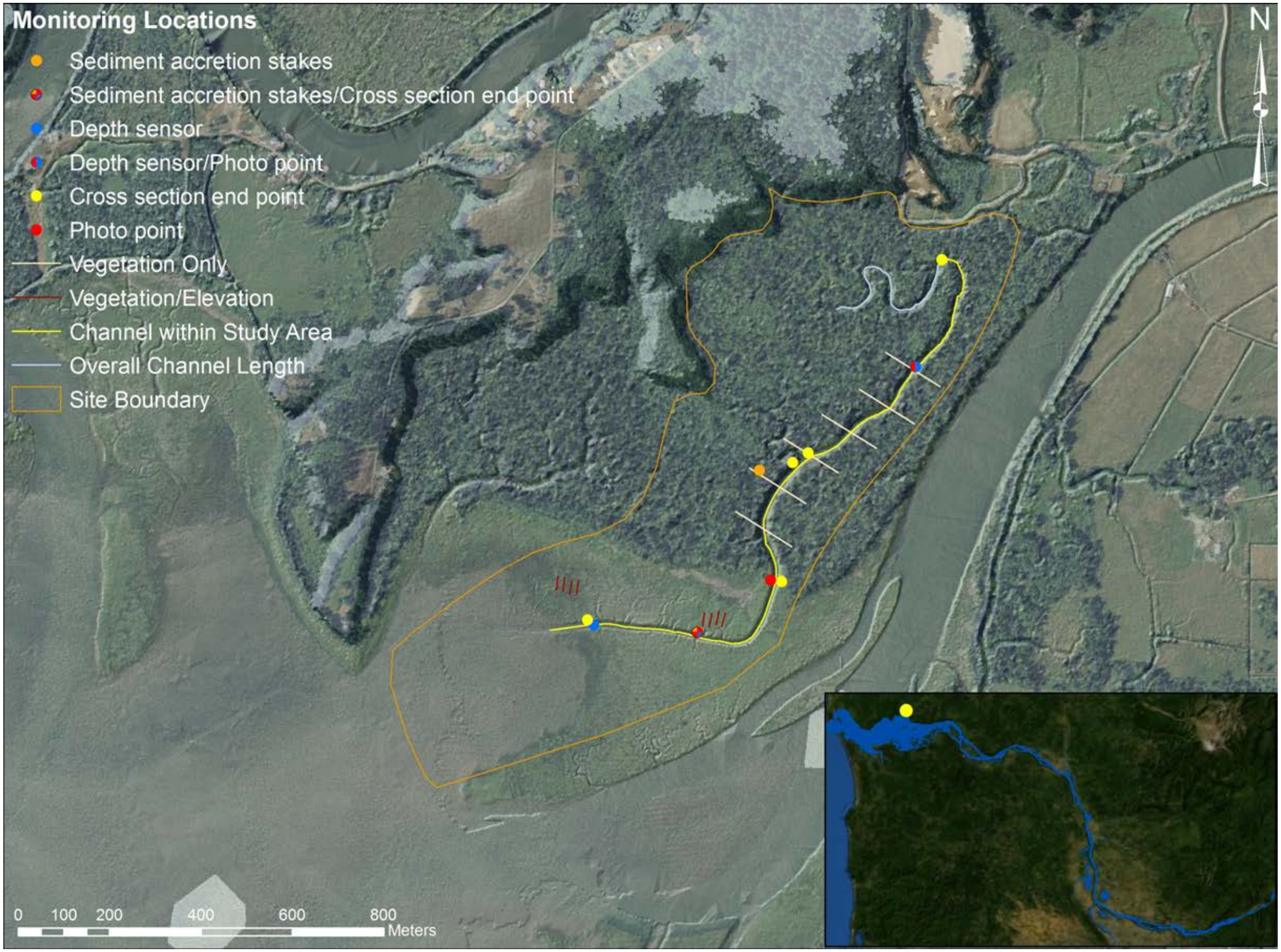


Figure A.40. Map showing the Secret River Marsh and Swamp sites.

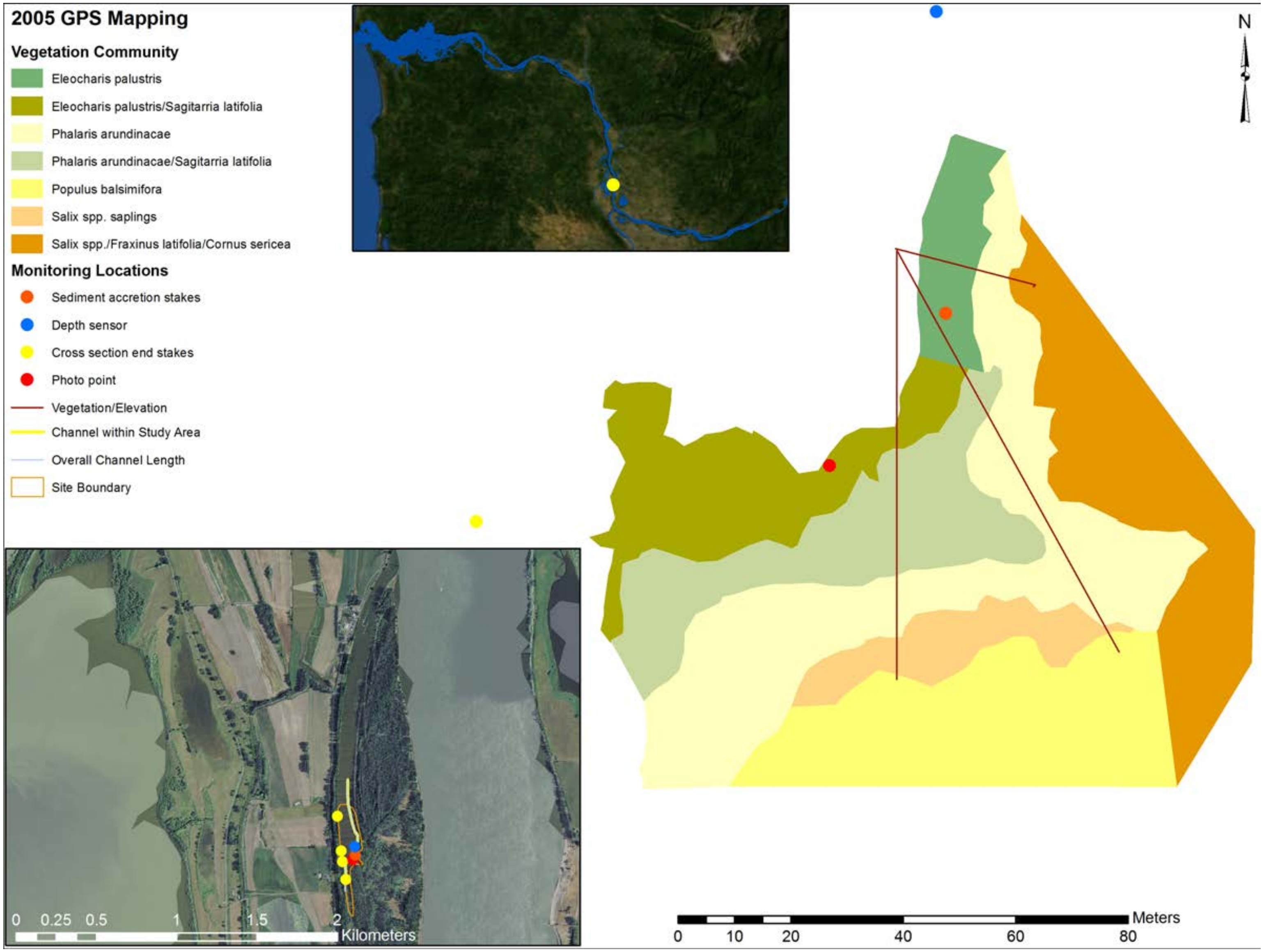


Figure A.41. Map showing the Sauvie Island East Slough Marsh site.

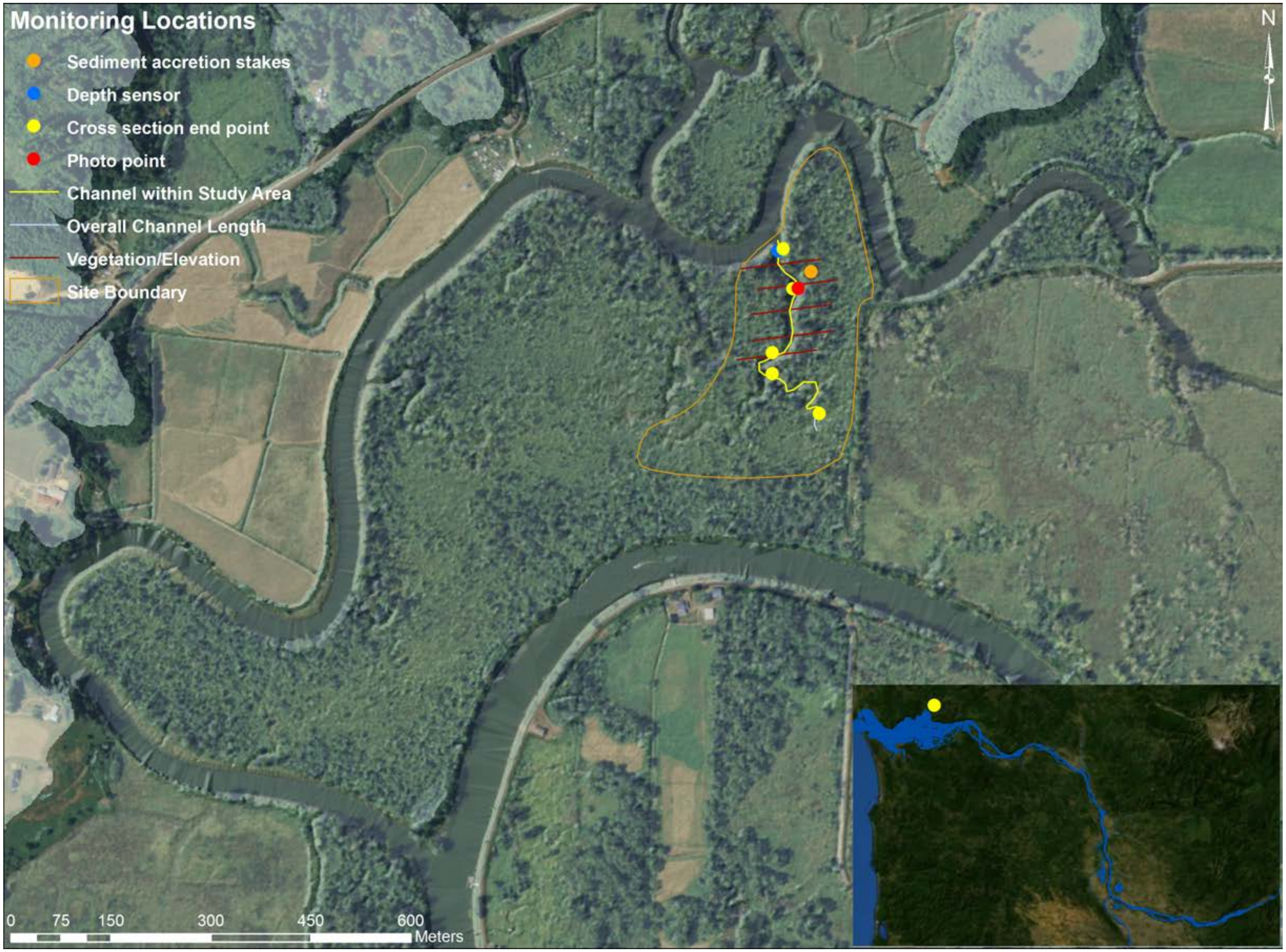


Figure A.42. Map showing the Seal Slough Swamp site.

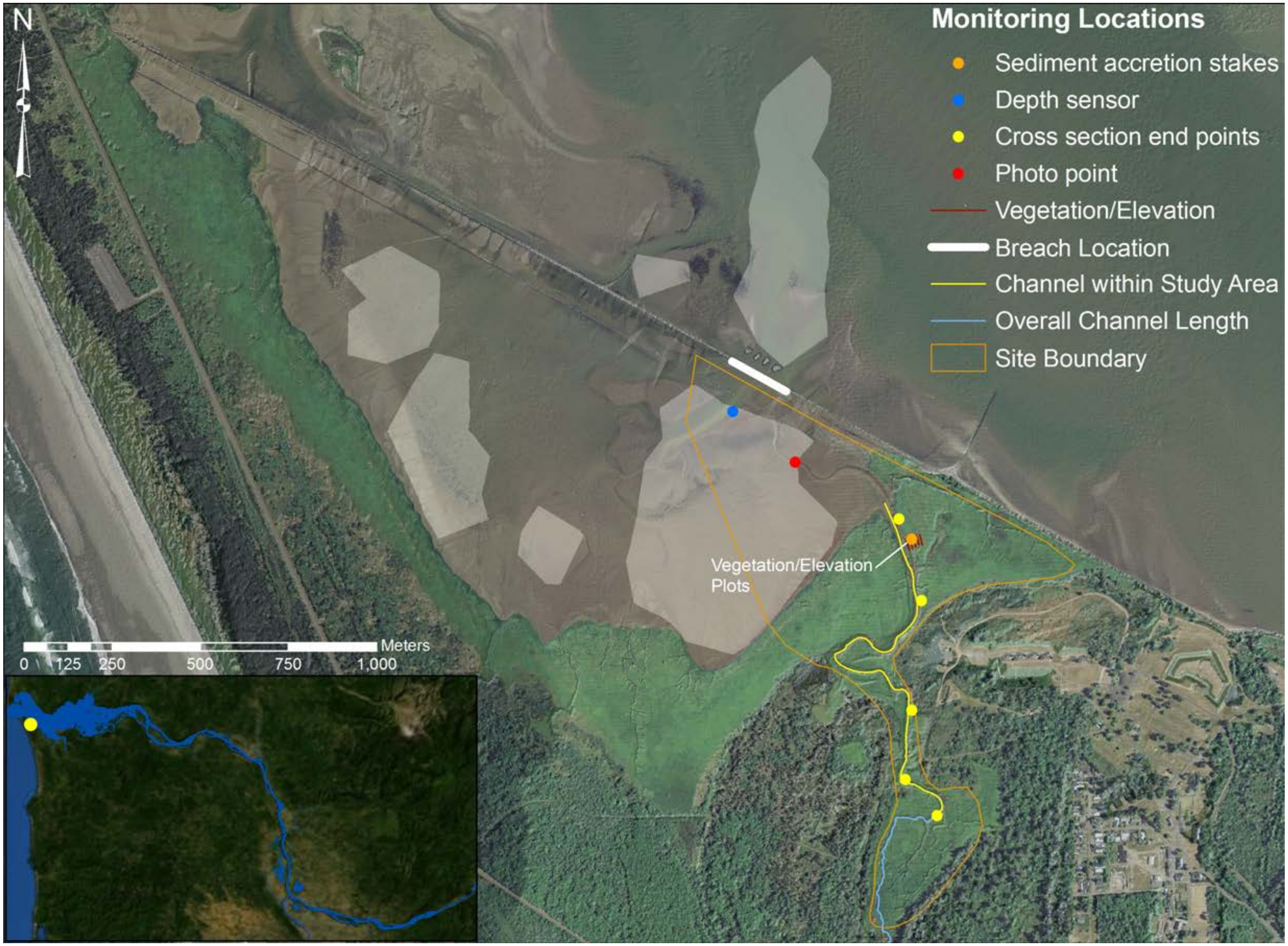


Figure A.43. Map showing the Trestle Bay Dike-breach Marsh site.

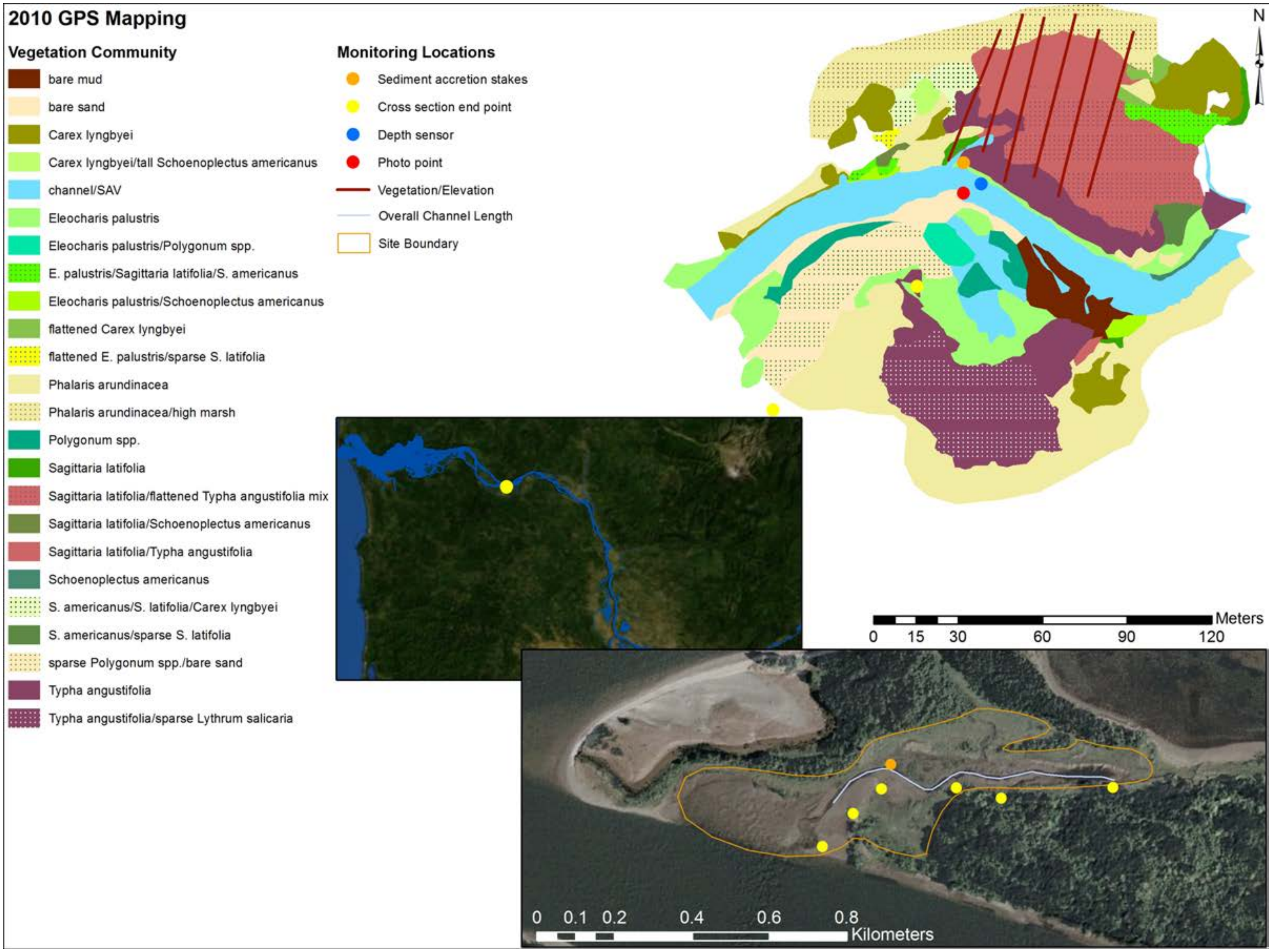


Figure A.44. Map showing the Wallace Island West Marsh site.

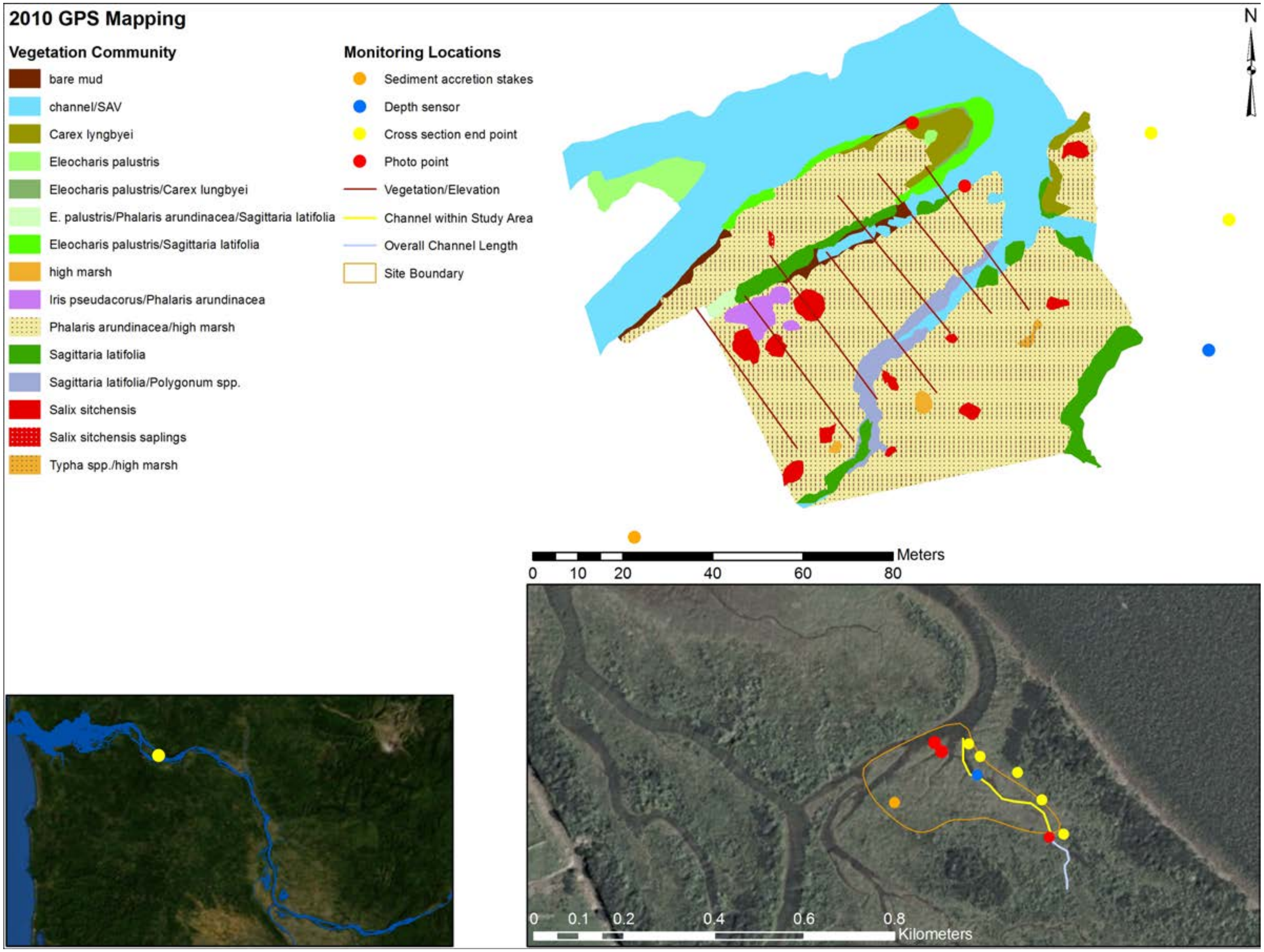


Figure A.45. Map showing the Whites Island Marsh site.

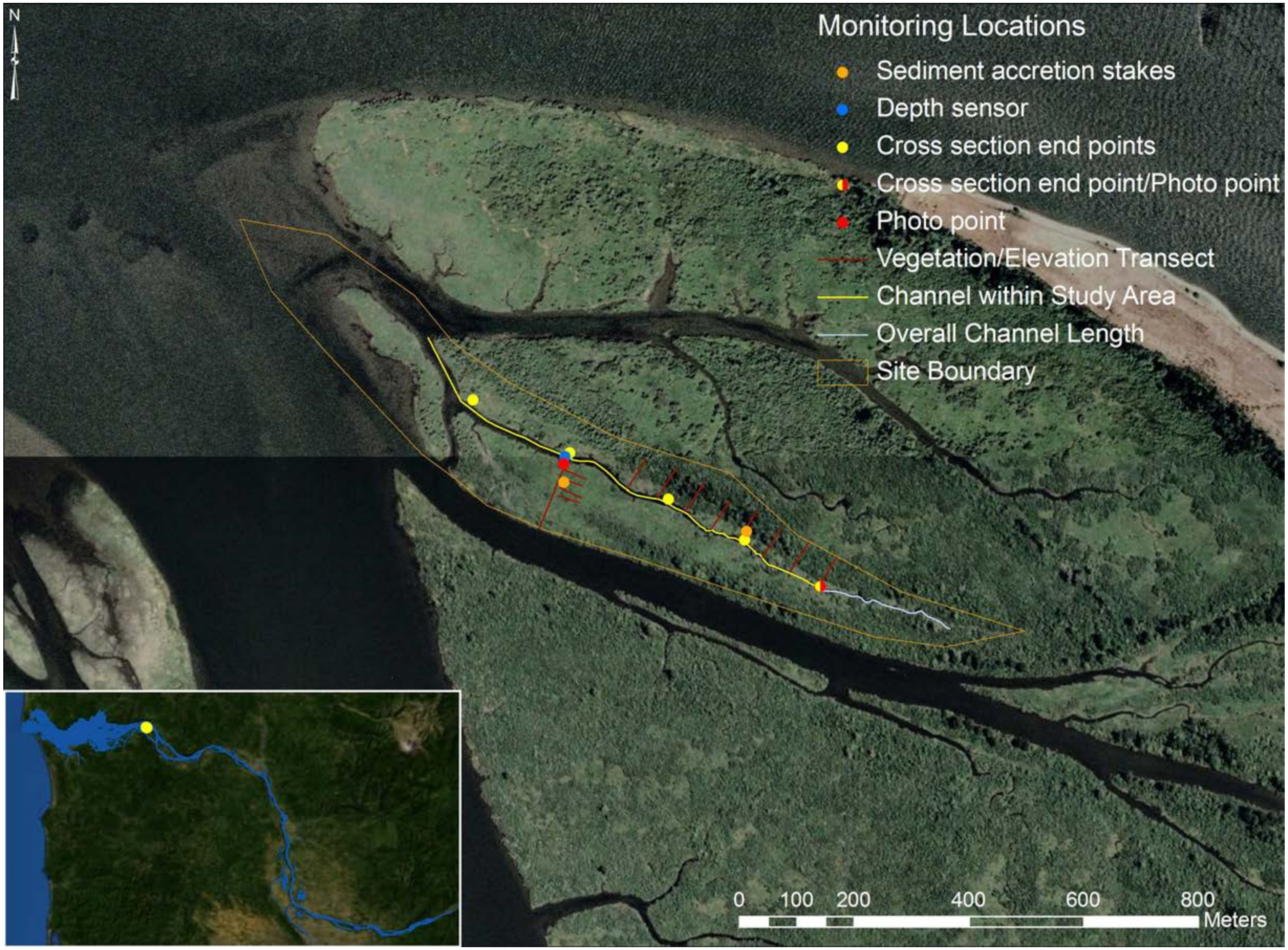


Figure A.46. Map showing the Welch Island Marsh and Shrub Wetland sites.

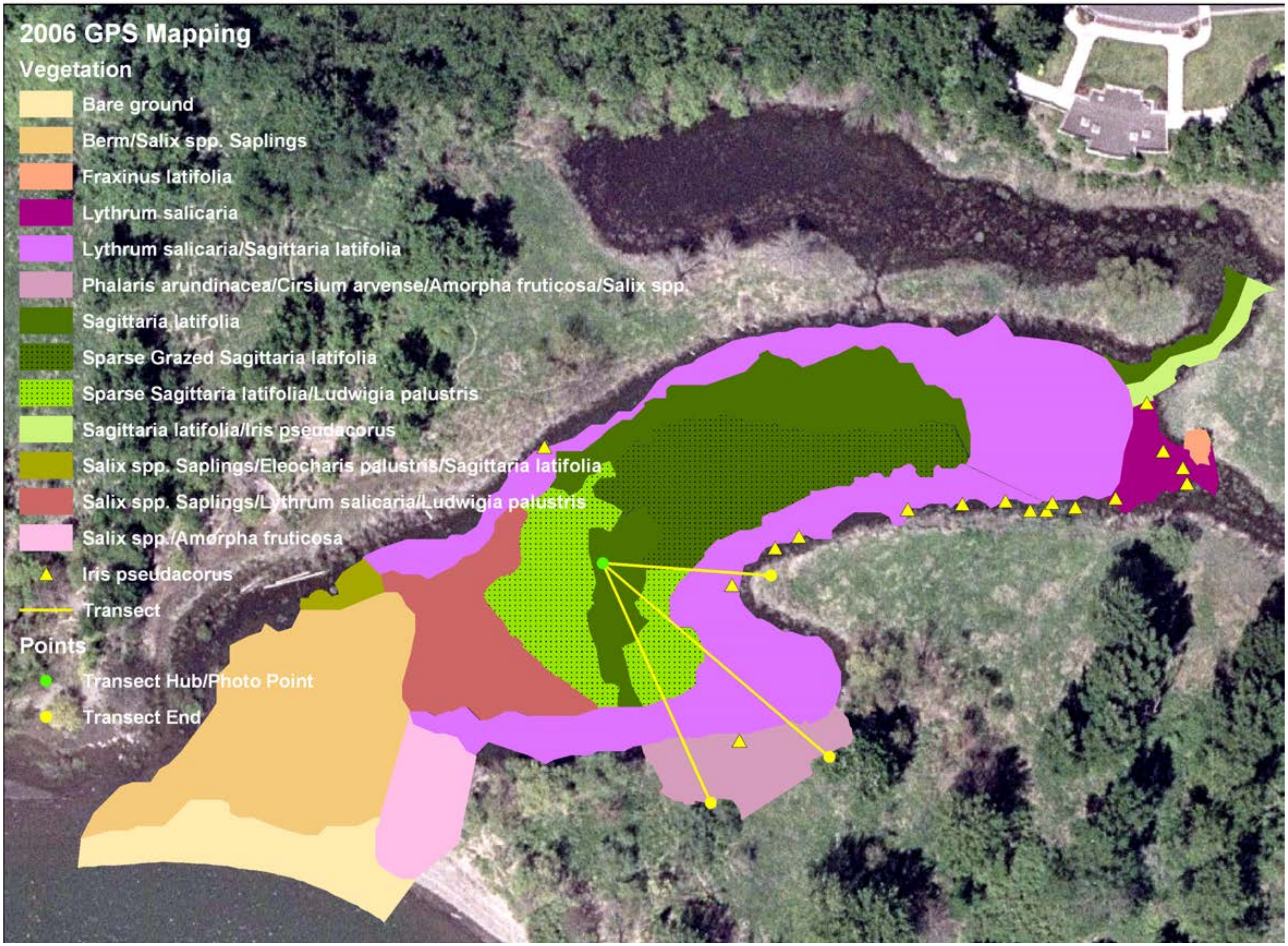


Figure A.47. Map showing the Water Resources Center Marsh site.

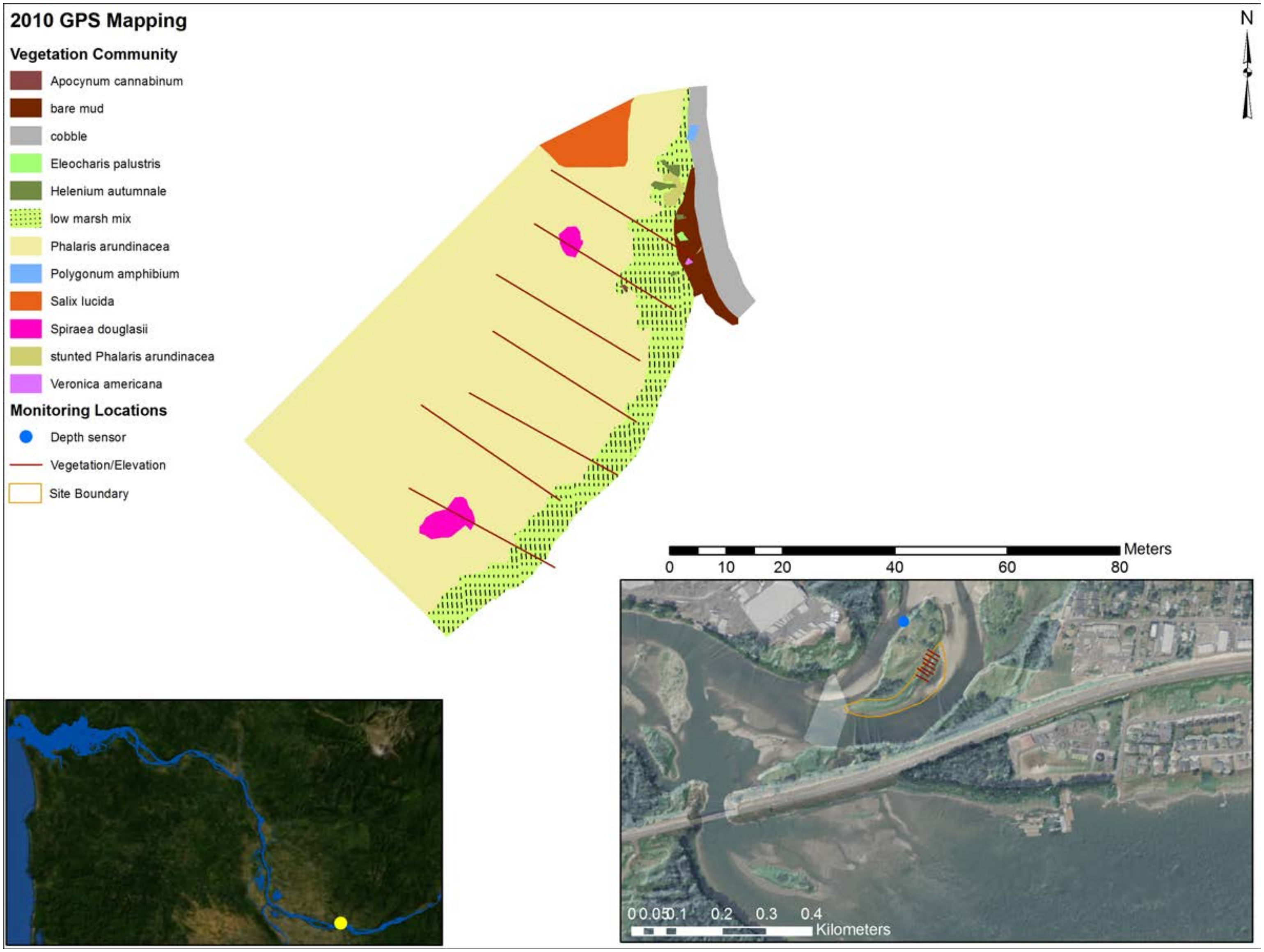


Figure A.48. Map showing the Washougal River Mouth Marsh site.

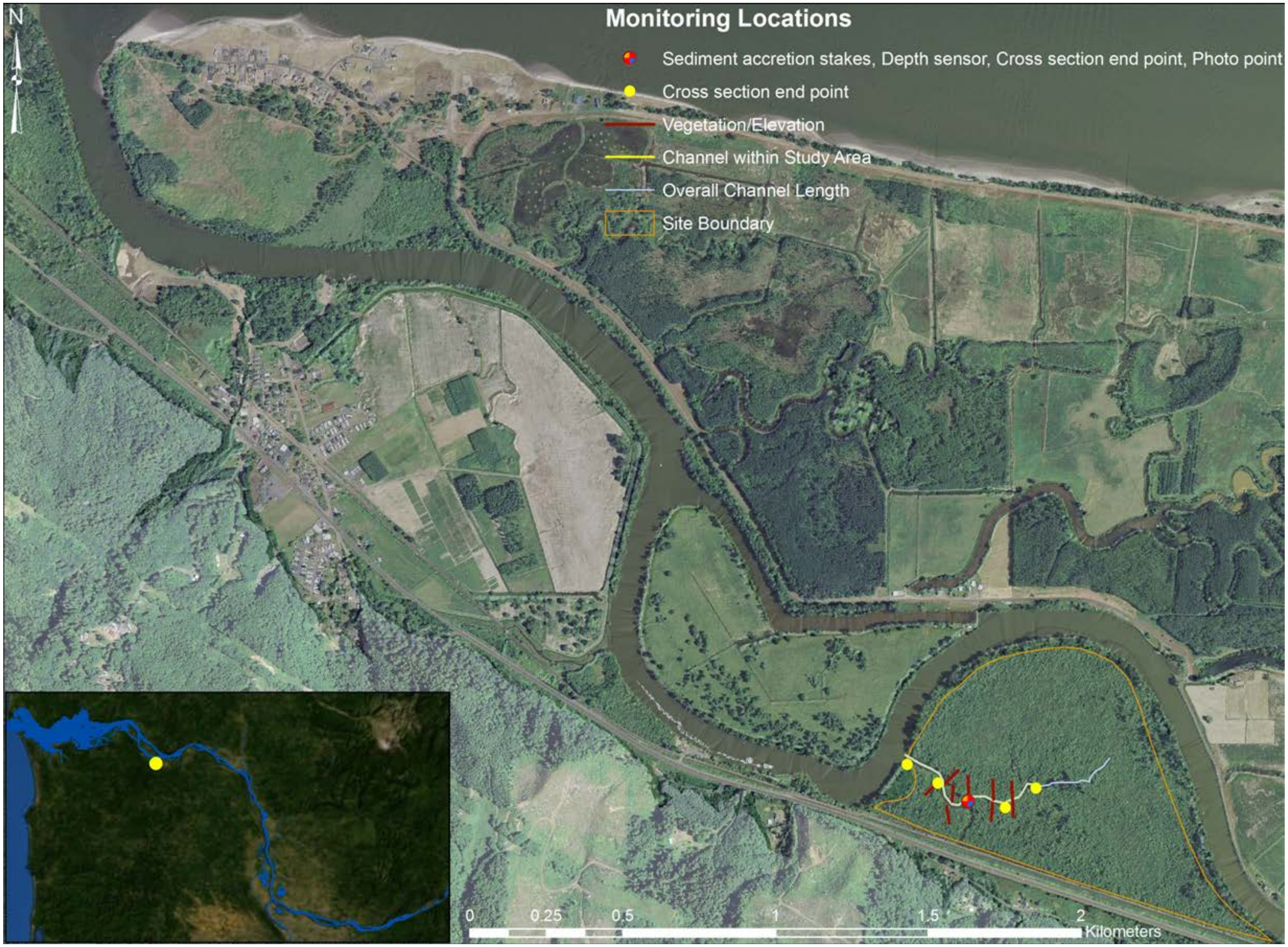


Figure A.49. Map showing the Westport Slough Shrub Wetland site.

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