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Concurrent Assessment of Eelgrass Beds (*Zostera marina*) and Salt Marsh Communities along the Estuarine Gradient of the South Slough, Oregon

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ABSTRACT

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Salt marshes, eelgrass beds (*Zostera marina*), and benthic macroalgae frequently occur in close proximity along the steep tidal channels of Pacific Northwest estuaries, where they constitute distinct patches of transitional land-margin habitat. The eelgrass beds and adjacent salt marshes within the South Slough National Estuarine Research Reserve, Oregon, provide an opportunity to investigate commonalities and differences between two ecological-indicator communities that are often separated by only a few meters. The principal objectives of this study are to establish a series of adjacent eelgrass and salt marsh assessment and monitoring sites within different hydrographic regions of the South Slough estuary and to characterize initial temporal and spatial changes in the composition of the plant communities in accordance with new field protocols developed by the National Estuarine Research Reserve System (NERRS) and by SeagrassNet. Eelgrass beds and emergent salt marsh communities were sampled at three study sites located along the estuarine gradient of the South Slough (43°20′ N, 124°19′ W). Study sites were established at (1) Collver Point (marine-dominated region), (2) Valino Island (polyhaline region), and (3) Danger Point (riverine/mesohaline region). Ambient water parameters and water column nutrients were monitored throughout the study period (2004–05) as part of the South Slough NERR System-Wide Monitoring Program. Periodic assessment of Rod Sediment Elevation Table (RSET) stations established within the eelgrass beds revealed that surface elevation increased at a rate of about 0.84 mm mo^{-1} at the Valino Island site but decreased at a rate of about 0.44 mm mo^{-1} at the Danger Point study site. Metrics of community richness, diversity, and species equitability indicate that the adjacent salt marshes and eelgrass beds develop community characteristics within the South Slough that are strongly reflective of their location along the estuarine gradient. The community composition, spatial cover, and density of macrophytes within the salt marsh and eelgrass communities were very similar between the Collver Point and Valino Island study sites, where mean monthly salinities in the tidal channel ranged between 25 and 32, and water temperatures were moderate (10–16 °C) throughout the year. In contrast, the salt marsh communities and eelgrass beds were distinctly different at the Danger Point study site, where mean monthly salinities ranged between 10 and 20, and water temperatures were much warmer in summer (20 °C) than in winter (9 °C). These intertidal salt marshes and eelgrass beds are highly productive and ecologically important components of the South Slough estuarine ecosystem despite their low richness of macrophyte species and relatively low metrics of community diversity. Recognition of these landscape-level differences in composition and productivity of submersed and emergent vegetation is important in the South Slough because the plant communities have potential to serve as reference sites to gauge the effectiveness of off-site habitat restoration and enhancement efforts.

ADDITIONAL INDEX WORDS: *Eelgrass,* Zostera marina*, salt marsh, sedimentation, nutrients, diversity, estuarine gradient.*

INTRODUCTION

Throughout the Pacific Northwest region of North America, eelgrass beds (*Zostera marina*) and benthic macroalgae constitute the primary form of submersed aquatic vegetation that occupies the lowest fringe of the intertidal landscape (BORDE *et al.,* 2003; THOM *et al.,* 2003), whereas diverse communities of emergent salt marsh vegetation thrive at the middle and upper intertidal elevations. The ecological functions of estuarine eelgrass beds and salt marshes can be considered as separate, yet related, indicators of the condition of estuarine habitats. There is a pressing need to develop robust and reliable metrics that accurately describe the ecological characteristics of these distinct vegetation communities as biotic indicators of estuarine ecosystem health (ADAMS and BORTONE, 2005; GOOD, 2000). Recognition of regional differences in composition and productivity of submersed and emergent vegetation is important in Pacific Northwest estuaries because these plant communities provide an essential pathway for the transfer of dissolved nutrients, organic ma-

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terials, and coastal sediments between terrestrial and aquatic ecosystems.

Salt marshes, eelgrass beds (*Zostera marina*), and benthic macroalgae frequently occur in close proximity along the steep tidal channels of Pacific Northwest estuaries, where they constitute distinct patches of transitional land-margin habitat (Rumrill, 2006). The eelgrass beds and adjacent salt marshes found within the South Slough National Estuarine Research Reserve, Oregon, provide an opportunity to investigate commonalities and differences between two ecological indicators that are often separated by only a few meters and to compare the utility of future monitoring efforts that focus on either or both of these vegetative communities. Concentrations of dissolved nutrients, rates of sedimentation, and changes in the composition and productivity of submersed aquatic vegetation and emergent salt marshes are all widely considered as sensitive indicators of estuarine habitat conditions that are responsive to local differences in natural dynamics and anthropogenic perturbations (Bortone, 2005; Short and Coles, 2001). Consequently, concurrent investigations of the salt marsh and eelgrass systems can be coupled with information about benthic macroalgae, nutrients, and sedimentation to provide a more complete description of the ecological status and condition of plant communities in Pacific Northwest estuaries.

Despite their low macrophyte species diversity, the linked communities of intertidal salt marshes, eelgrass beds, and adjacent macroalgal beds are highly diverse, productive, and stable components of estuarine ecosystems (Borde *et al.,* 2003; Hemmiga and Duarte, 2000; Thom *et al.,* 2003; Travis and Hester, 2005). Investigation of factors that contribute to local differences in the community composition of estuarine salt marshes and eelgrass beds is intriguing because low taxonomic richness within these communities contradicts the view that species diversity is positively correlated with enhanced ecosystem functions (Loreau *et al.,* 2001; Reusch and Hughes, 2006). The rationale for our concurrent approach of characterizing eelgrass beds and salt marsh communities is that the combination of time-series information from several different types of ecological components (ambient water column parameters, dissolved nutrients, salt marshes, eelgrass beds, and macroalgae) provides a more robust indicator of the condition of plant communities in the South Slough estuary than the limited information derived from any single component.

About 95 ha of native eelgrass (*Zostera marina*) occur within the South Slough estuary (Rumrill, 2006). Eelgrass beds are expansive in the marine-dominated and polyhaline regions, particularly within the open tideflats at Barview Wayside, Metcalf Marsh, Brown's Cove, and near Valino Island, where they occur as broad meadows in the open tideflats and as narrow fringe beds along the edge of the deep tidal channels. In contrast, the distribution of *Z. marina* is fragmented in the mesohaline and oligohaline regions of the estuary, where plants occur sporadically in 1 to 3 m^2 patches and smaller clusters of three to six plants along the edge of the tidal channel. However, dense beds of *Z. marina* occur in the riverine/mesohaline region of the South Slough within the Winchester Creek and Talbot Creek tidal channels. These beds of *Z. marina* occur within the +1.2 to −2.1 m Mean Lower Low Water (MLLW) tidal range, and they exert important influences on local flow patterns, sedimentary regimes, and the distribution of infaunal and epibenthic organisms in the lowest intertidal zone. Dense beds of dwarf eelgrass (*Zostera japonica*) occur throughout the estuary higher in the intertidal zone (+1.4 to +0.6 m MLLW), where colonization by the rooted vegetation has altered sediment characteristics and infaunal, invertebrate communities (Posey, 1988).

About 198 ha of emergent salt marshes occur within the intertidal region of the South Slough estuary (Graves, 1991). These salt marsh communities are dominated by a mixed species assemblage of 25 to 30 common emergent vascular plants (Cornu and Sadro, 2002; Ewing and Seebacher, 1997; Rumrill, 2006). Within the marine-dominated and polyhaline regions of the estuary, the low intertidal marshes typically include mixed assemblages of pickleweed (*Salicornia virginica*), saltgrass (*Distichlis spicata*), fleshy jaumea (*Jaumea carnosa*), seaside arrowgrass (*Triglochin maritimum*), and Lyngbye's sedge (*Carex lyngbyei*). Small isolated individuals of the threatened salt marsh bird's-beak (*Cordylanthus maritimus palustris*), a federally recognized candidate species under the *Endangered Species Act of 1973* (ESA; 16 *U.S.C.* §1531–1544, 87 *Stat.* 884, as amended, P.L. 93-205; Eastman, 1990), occur within the fringing marshes at several locations within the South Slough. Higher intertidal marsh communities are characterized by dense stands of tufted hairgrass (*Deschampsia cespitosa*), saltgrass, Lyngbye's sedge, and creeping bentgrass (*Agrostis stolonifen*). Scattered patches of Pacific silverweed (*Potentilla pacifica*) and gumweed (*Grindelia integrifolia*) are found at the highest intertidal elevations, and communities of springbank clover (*Trifolium wormskjoldii*), Douglas aster (*Aster subspicatus*), yarrow (*Achillea* spp.), and velvetgrass (*Holcus lanatus*) typically mark the transition to the terrestrial upland community. The composition of salt marsh communities differs substantially within the more riverine/mesohaline and oligohaline regions of the estuary. Low intertidal marshes are exposed to greater freshwater influence and are characterized by dense stands of Lyngbye's sedge, Baltic rush (*Juncus balticus*), saltbush, and fleshy jaumea. At higher tidal elevations, the salt marsh community includes Lyngbye's sedge, creeping bentgrass, tufted hairgrass, saltgrass, seaside arrowgrass, and saltbush. Dense stands of slough sedge (*Carex obnupta*) mark the transitional boundary to freshwater marshes and the uplands. Emergent salt marsh vegetation typically occurs in the estuary within an elevational range of +1.3 to +2.4 m above MLLW (Rumrill, 2006).

The principal objectives of this investigation were (1) to establish a series of adjacent eelgrass and salt marsh assessment and monitoring sites within different hydrographic regions of the South Slough estuary, and (2) to characterize temporal and spatial changes in the composition of the plant communities in accordance with new field protocols developed by the National Estuarine Research Reserve System (Moore, 2003). Information generated by the baseline surveys will be used in the future to address a series of immediate (short-term) questions and ongoing (long-term) management issues. For example, the sampling program is structured to answer several questions. How tightly linked are the seasonal ecological characteristics of eelgrass beds and salt marshes among the different hydrographic regions of the South Slough estuary? Do all eelgrass beds exhibit similar seasonal cycles of spatial cover, density, and biomass regardless of their position along the estuarine gradient? To what extent do the seasonal and annual dynamics of eelgrass beds and emergent salt marshes reflect changing conditions in the nearshore Pacific Ocean *vs.* interannual differences in freshwater input from the local watershed? Further characterization of the eelgrass beds and salt marsh communities is required to answer these questions. With continued monitoring and periodic assessments, we anticipate that the study sites within the South Slough estuary may serve as local and regional reference areas to better understand ecological changes within different hydrodynamic regions. In addition, the reference areas may have added utility as a gauge for the effectiveness of local and regional salt marsh and eelgrass mitigation and restoration efforts.

METHODS

Study Sites

South Slough (43°20′ N, 124°19′ W) is an elongated, shallow tidal inlet located near the mouth of Coos Bay, Oregon (Rumrill, 2006; Figure 1). The estuarine subsystem encompasses several distinct hydrographic regions, and three study sites were established along the estuarine gradient, with one study site within each hydrographic region (Figures 2 and 3). The Collver Point study site (43°19′47″ N, 124°19′8″ W) is located in the marine-dominated region and consists of a sandstone headland with adjacent mudflats, eelgrass beds, a cobble terrace, and a fringing, low, silty salt marsh (Akins and Jefferson, 1973). The Valino Island study site (43°18′50″ N, 124°19′5″ W) is located in the polyhaline region of the estuary and consists of expansive sand and mudflats, extensive eelgrass beds, and a small, low, sandy salt marsh. The Danger Point study site (43°16′58″ N, 124°19′17″ W) is located in the riverine/mesohaline region and consists of a mature high salt marsh, mudbanks, and a fringing eelgrass bed along the length of a narrow tidal channel. Each of these study sites is located in close proximity to an existing long-term estuarine water quality monitoring station operated by the National Estuarine Research Reserve System-Wide Monitoring Program (NERR SWMP; Owen and White, 2005). Nearly continuous datalogger recordings were generated at each study site for the duration of the study (2004–05) by an automated multiparameter datasonde (Model 6600 Extended Deployment System, YSI Incorporated, Yellow Springs, Ohio) situated about 0.5 m above the bottom of the estuarine tidal channel. The datasondes recorded measurements every 30 minutes for several water column parameters, including water level, temperature, conductivity, salinity, pH, dissolved oxygen, turbidity, and fluorescence. In addition, water column samples were collected on a monthly basis at high and low tides to determine spatial and temporal changes in the availability of nutrients, including nitrate, nitrite, ammoni-

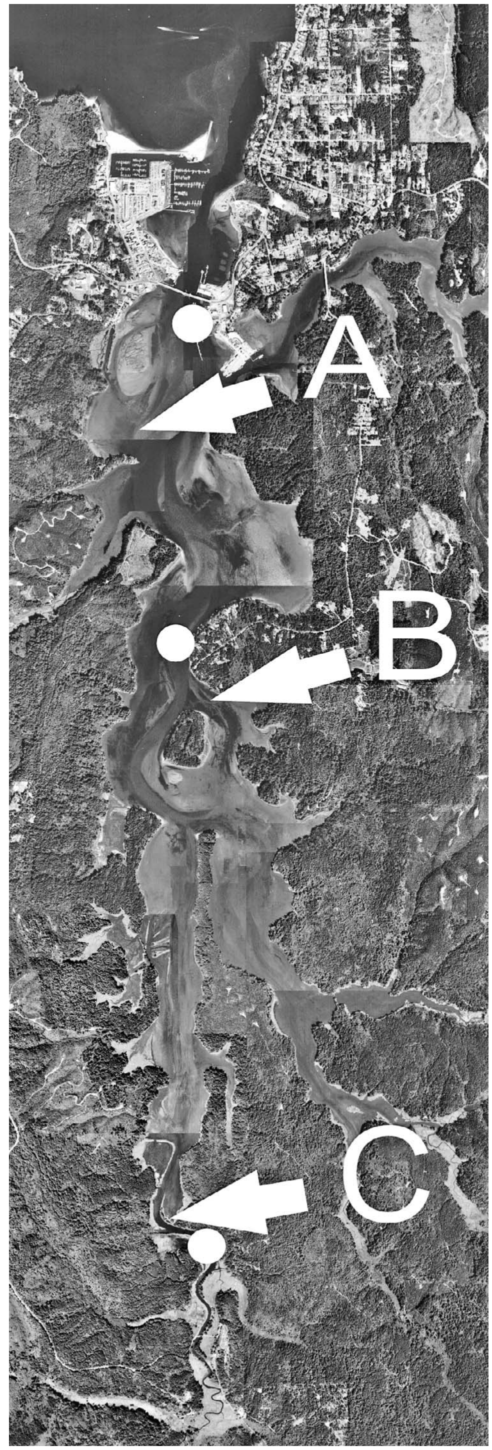

Figure 1. Location of study sites along the estuarine gradient of the South Slough, Oregon. Study sites for salt marshes and eelgrass beds were located at: (A) Collver Point (marine-dominated); (B) Valino Island (mesohaline); and (C) Danger Point (riverine). White circles indicate location of NERR / SWMP estuary water monitoring stations at Charleston Bridge, Valino Island, and Winchester Creek.

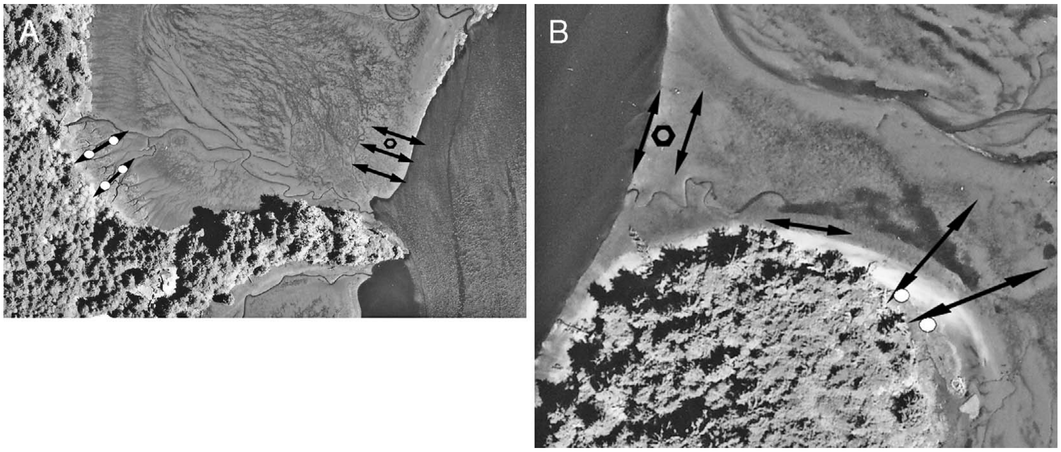

Figure 2. Location and orientation of transect lines within salt marsh and eelgrass habitat at the (A) Collver Point and (B) Valino Island study sites. Double-ended arrows indicate location of transect lines that traverse salt marshes and eelgrass beds at each study site. White circles indicate location of water table wells in salt marshes; black hexagon indicates location of RSET station adjacent to eelgrass bed.

um, silica, and orthophosphate, as well as concentrations of chlorophyll and phaeopigments.

Eelgrass and Salt Marsh Reference Sites

Based on prior knowledge and characterization of the emergent marsh and submerged vegetation communities, we selected a series of paired eelgrass and salt marsh reference areas at each study site that are representative of natural vegetation communities along the South Slough estuarine gradient (Figures 1–3). We used existing high-resolution aerial photos (1:10,000–1:12,000) taken in 2002 and 2003 to delineate and define the boundaries of our target eelgrass and salt marsh communities. We also used existing digital orthophotos, oblique aerial photos, and recent (2002) IKONOS satellite (Geo, 5 m, color) remote-sensing images to develop a base map for each study site.

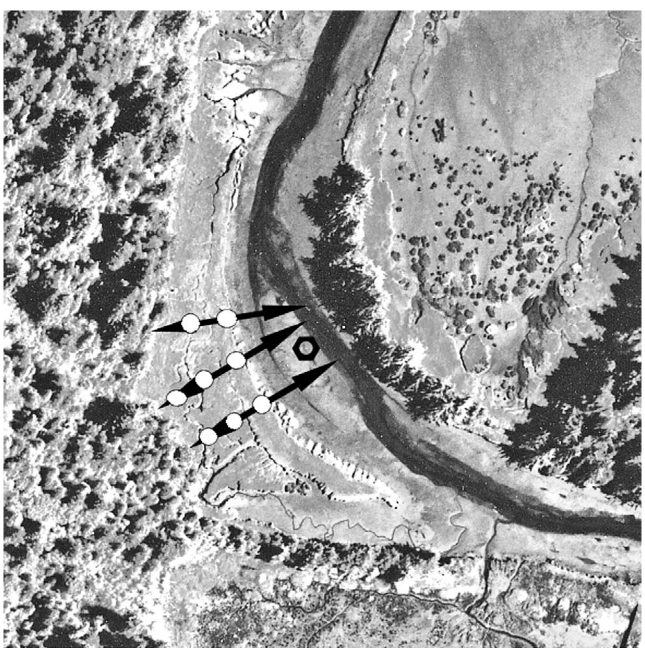

Figure 3. Location and orientation of transect lines within salt marsh and eelgrass habitat at the Danger Point study site. Double-ended arrows indicate location of transect lines that traverse salt marsh and eelgrass bed. White circles indicate location of water table wells in salt marshes; black hexagon indicates location of RSET station adjacent to eelgrass bed.

Sampling of Emergent Vegetation

We established two to three permanent transect lines at each study site (Figures 2 and 3), and each transect line (50–100 m) was oriented to traverse the elevation gradient from the upland-marsh boundary (about +2.6 m MLLW) to the marsh-mudflat boundary (about +1.4 m MLLW). Global Positioning System (GPS) coordinates were recorded at the beginning and end of each transect line. Wooden stakes were placed to mark the locations of about 20 permanent 0.25-m^2 sample plots located at evenly spaced intervals along the transect lines. We also installed a series of 14 groundwater wells (1-in polyvinyl chloride pipe, 50 cm deep) along the transect lines within the salt marsh study sites (Collver Point, 4 wells; Valino Island, 2 wells; Danger Point, 8 wells) to measure changes in the depth of the water table relative to the marsh surface.

The annual period has been described previously for salt marsh plants within the South Slough estuary (FRITZ, 2001; RUMRILL, 2006). The period of peak aboveground biomass occurs from June to early August, and marsh biomass reaches the lowest point in the winter (January–February). To address concurrent changes in the adjacent salt marshes and eelgrass beds, we conducted nondestructive surveys within the 0.25-m^2 permanent plots and recorded the species composition of salt marsh plants during July to August 2004, February 2005, and July 2005. For each quadrat, we recorded visual estimates of spatial cover for each plant species (at 5%

cover intervals) and estimated spatial cover for other cover categories (*i.e.,* bare mud, algal mat, debris, *etc.*). We also counted the number of shoots or stems for each plant species, measured the maximum canopy height, and recorded the distance from the marsh surface to the water table within the groundwater wells.

Sampling of Eelgrass Beds

We established two to three permanent transect lines within eelgrass beds at each of the Collver Point, Valino Island, and Danger Point study sites (Figures 2 and 3). Each transect line was oriented to traverse the elevation gradient from the marsh-eelgrass boundary (about +1.5 m MLLW) to the lowest edge of the eelgrass bed (about −2 m MLLW). Whenever possible (*i.e.,* Valino Island and Danger Point; Figures 2 and 3), the transect lines ran continuously through the salt marshes and adjacent eelgrass beds. At the Collver Point study site, the eelgrass transect lines were separated from the salt marsh transect lines by about 90 to 110 m of unvegetated mudflats (Figure 2). GPS coordinates were recorded at the beginning and end of each transect line. Wooden stakes were placed to mark the locations of about 20 permanent 0.25-m^2 quadrat plots located at evenly spaced intervals along the transect lines.

The period of peak eelgrass density and biomass occurs within the South Slough estuary from July to early August (Rumrill, 2006; Rumrill and Christy, 1996; Thom *et al.,* 2003). To characterize spatial and temporal changes in the eelgrass beds, we conducted nondestructive surveys along the transect lines during July to August and November of 2004, and in February, May, and July of 2005. During each survey, we recorded the species composition of eelgrass plants (*Z. marina* and *Z. japonica*) within each quadrat, conducted visual estimates of spatial cover for each plant species (at 5% cover intervals), and measured shoot density, the number of flowering plants, blade length/maximum canopy height, and blade width. We conducted visual estimates of spatial cover for other cover categories (*i.e.,* unvegetated mud, shell rubble, macroalgae, *etc.*). We installed a Rod Surface Elevation Table (RSET; Cahoon *et al.,* 2002) and three feldspar horizon markers within the eelgrass bed at each study site to establish a baseline for future measurements of sediment deposition and subsidence. Voucher specimens of eelgrass blades, flowers, seeds, and rhizomes were collected and preserved.

SeagrassNet Sampling of Eelgrass Beds

We conducted additional sampling of the eelgrass beds at the Valino Island study site to evaluate application of the SeagrassNet sampling protocol (Short *et al.,* 2006) within the South Slough estuary and to provide data that are complementary to information gathered along the adjacent eelgrass-marsh transects. Three permanent 25-m transects were established parallel to the shoreline near the upper, middle, and lower edge of the eelgrass bed at the Valino Island study site (Figure 2). Sampling along the transect lines was repeated quarterly (July and November 2004, and February, May, and July 2005). In accordance with the SeagrassNet protocol, light-intensity dataloggers (HOBO LI, Onset Computer Corporation, Bourne, Massachusetts) were deployed at the midpoint of two transect lines and on the adjacent shoreline for a period of 2 weeks before sampling to record measurements of surface light over a representative time period, which is likely to include cloudless days as well as cloudy and foggy days. We have successfully deployed the light-intensity meters (encased in waterproof containers) within eelgrass beds and commercial oyster longlines (Rumrill and Poulton, 2003) and have previously developed correlation equations to compare digital output from the individual Onset-HOBO meters (lumens) to measurements of light quanta (μmol m^{-2} s^{-1}; $r^2 = 0.857$) and photosynthetically active radiation (μmol m^{-2} s^{-1}; $r^2 = 0.917$) collected by the South Slough NERR SWMP meteorological station.

SeagrassNet sampling was conducted within 12 permanent random plots (0.25-m^2 quadrats), along each of the three 25-m transect lines (total of 36 quadrats within the Valino Island eelgrass bed). Digital archival photos were taken of each quadrat, and field measurements were recorded for spatial cover (percentage), shoot density, canopy height/blade length, evidence of grazing, number of flowering plants, and the spatial extent of other cover categories (*i.e.,* unvegetated mud, shell rubble, macroalgae, *etc.*). Biomass cores (0.0035 m^2) were collected at a distance of 0.5 m from each quadrat and sieved in the field (through 1-mm mesh), and the contents were placed into ziplock bags and returned to the laboratory for determination of dry weights of the aboveground (leaves and sheaths) and belowground (rhizomes) components. Sediment cores (three per transect) were collected with a sawed-off 60-ml syringe at the mid point of each transect for analysis of sediment grain size and organic content. We also measured the distance from the edges of the eelgrass bed to the primary and secondary tidal channels and from the shoreline to the shallowest edge of the bed to evaluate future changes in bed size and dimensions. Voucher specimens of each species of eelgrass (including shoots, flowers, seeds, and rhizomes) were preserved, and duplicate specimens were sent to SeagrassNet (University of New Hampshire) for archival and storage.

RESULTS

Estuarine Water Parameters and Nutrients

Substantial temporal and spatial differences occurred in the series of ambient water column parameters measured along the estuarine gradient at the Collver Point, Valino Island, and Danger Point study sites (Table 1). In general, water temperatures were warmer in spring and summer and cooler in fall and winter. Mean water temperatures were coolest in the marine-dominated region (Collver Point) in the spring and summer, when they averaged 13.9 to 14.4 °C, and warmest in the riverine/mesohaline region (Danger Point), where they averaged 15.6 to 20.4 °C. The thermal gradient was reversed in fall and winter when average water temperatures were coolest (9.2 °C) within the riverine region (Danger Point) and warmest near Collver Point (10.5 to 10.6 °C; Table 1). Monthly mean salinities ranged between 32.9 (July 2004) and 27.8 (May 2005) at the Collver Point site, between 32.3 (July 2004) and 25.3 (May 2005) at the Valino Island

Table 1. *Summary of water quality parameters measured in 2004–05 at three study sites within the South Slough estuary, Oregon. Measurements recorded with multiparameter datasondes placed in the tidal channel near the Collver Point (marine-dominated), Valino Island (polyhaline), and Danger Point (mesohaline) study sites. Values shown are mean (±SD) for datalogger measurements recorded every 30 min over the entire month. Sample size (*n*) indicates number of datalogger recordings.*

Study Site*	July 2004	November 2004	February 2005	May 2005	July 2005
Collver Point					
Sample size (*n*)	1440	1370	1324	1476	1468
Temperature (°C)	14.29 (2.44)	10.50 (0.72)	10.59 (0.63)	14.41 (1.56)	13.96 (2.57)
Salinity (psu)	32.97 (0.65)	30.45 (1.67)	29.99 (1.86)	27.84 (2.77)	31.18 (1.19)
DO (mg L^{-1})	8.88 (1.83)	8.93 (0.64)	9.66 (0.29)	9.14 (0.66)	8.77 (1.77)
Turbidity (NTU)	3.26 (6.09)	3.59 (1.71)	4.96 (11.72)	3.62 (2.92)	2.41 (1.74)
Valino Island					
Sample size (*n*)	1381	1390	1300	1439	1422
Temperature (°C)	16.58 (2.19)	10.32 (0.89)	10.38 (0.88)	15.24 (1.34)	15.94 (2.45)
Salinity (psu)	32.26 (1.35)	28.70 (2.66)	28.48 (2.76)	25.27 (3.91)	30.19 (1.82)
DO (mg L^{-1})	6.26 (2.68)	8.57 (0.49)	9.12 (0.45)	8.56 (0.81)	8.29 (1.71)
Turbidity (NTU)	11.28 (10.52)	4.29 (2.09)	4.67 (4.59)	5.03 (19.57)	3.85 (11.47)
Danger Point					
Sample size (*n*)	1446	1391	1297	932	1419
Temperature (°C)	20.41 (1.87)	9.24 (1.48)	9.25 (1.67)	15.60 (2.16)	18.67 (1.85)
Salinity (psu)	19.92 (8.96)	13.04 (9.65)	12.99 (9.37)	9.82 (8.89)	15.04 (9.49)
DO (mg L^{-1})	6.32 (2.26)	9.36 (1.21)	9.60 (1.09)	8.32 (1.47)	6.92 (1.29)
Turbidity (NTU)	51.43 (127.60)	7.53 (6.09)	6.17 (6.05)	6.71 (4.16)	6.72 (4.95)

[1] psu = practical salinity units; DO = dissolved oxygen; NTU = nephelometric turbidity unit.

site, and between 19.9 (July 2004) and 9.8 (May 2005) at the Danger Point site. Monthly mean dissolved oxygen (DO) concentrations were generally high (8.3–9.7 mg L^{-1}) at all study sites throughout the year, with the exception of lower DO values (*ca.* 6.3 mg L^{-1}) at the Valino Island and Danger Point sites in July 2004 and at the Danger Point site (6.9 mg L^{-1}) in July 2005 (Table 1).

Substantial spatial and temporal differences also occurred in the concentrations of water-column nutrients sampled along the marine-to-freshwater gradient of the South Slough (Table 2). Orthophosphate (PO_4) concentrations were always highest (0.03–0.04 mg L^{-1}) in the marine-dominated (Collver Point) and polyhaline (Valino Island) regions of the South Slough estuary and lowest in riverine/mesohaline region

Table 2. *Summary of nutrient concentrations measured in 2004–05 at three study sites within the South Slough estuary, Oregon. Nutrient concentrations were determined from water-column grab samples collected at low tide near the Collver Point (marine-dominated), Valino Island (polyhaline), and Danger Point (mesohaline) study sites. Values shown are mean (±SD).*

Study Site	July 2004	November 2004	February 2005	May 2005	July 2005*
Collver Point					
Sample size (*n*)	3	3	3	3	3
Orthophosphate (mg L^{-1})	0.0368 (0.0016)	0.0415 (0.0015)	0.0270 (0.0004)	0.0159 (0.0002)	0.0417 (0.0005)
Ammonium (mg L^{-1})	0.0264 (0.0003)	0.0053 (0.0004)	0.0347 (0.0003)	0.0113 (0.0018)	0.0233 (0.0006)
Nitrite + nitrate (mg L^{-1})	0.0065 (0.0007)	0.2196 (0.0100)	0.1374 (0.0006)	0.0163 (0.0006)	0.0511 (0.0004)
Chlorophyll-*a* (μg L^{-1})	3.0933 (0.2801)	1.6133 (0.0651)	1.0433 (0.0702)	9.5167 (0.6634)	5.3867 (1.1684)
Silica (mg L-1)	0.5913 (0.0413)	0.4953 (0.0155	1.2017 (0.0044)	1.1967 (0.1571)	na
Valino Island					
Sample size (*n*)	3	3	3	3	3
Orthophosphate (mg L^{-1})	0.0406 (0.0006)	0.0295 (0.0007)	0.0225 (0.0001)	0.0132 (0.0005)	0.0359 (0.0003)
Ammonium (mg L^{-1})	0.0192 (0.0020)	0.0582 (0.0037)	0.0361 (0.0002)	0.0195 (0.0019)	0.0258 (0.0007)
Nitrite + nitrate (mg L^{-1})	0.0040 (0.0008)	0.2064 (0.0039)	0.1373 (0.0001)	0.0313 (0.0005)	0.0372 (0.0002)
Chlorophyll-*a* (μg L^{-1})	4.2567 (0.8393)	2.2200 (0.1058)	1.4967 (0.0404)	11.9333 (1.5690)	7.8300 (1.0651)
Silica (mg L^{-1})	1.0193 (0.0025)	1.9773 (0.0012)	1.7701 (0.0009)	2.9288 (0.0477)	na
Danger Point					
Sample size (*n*)	3	3	3	3	3
Orthophosphate (mg L^{-1})	0.0052 (0.0008)	0.0048 (0.0004)	0.0029 (0.0001)	0.0022 (0.0001)	0.0053 (0.0003)
Ammonium (mg L^{-1})	0.0304 (0.0011)	0.0259 (0.0004)	0.0256 (0.0013)	0.0231 (0.0009)	0.0388 (0.0008)
Nitrite + nitrate (mg L^{-1})	0.0519 (0.0005)	0.3271 (0.0068)	0.4924 (0.0020)	0.7308 (0.0019)	0.1284 (0.0002)
Chlorophyll-*a* (μg L^{-1})	3.6033 (1.4049)	1.0667 (0.1050)	0.5500 (0.0400)	0.5067 (0.0416)	4.4200 (0.2427)
Silica (mg L^{-1})	2.8027 (0.1072)	2.9247 (0.1295)	0.8537 (0.0599)	0.0068 (0.0003)	na

* na = not applicable.

(Danger Point), indicating that the nearshore ocean waters are the most likely source. Concentrations of orthophosphate were lowest in spring (0.002–0.016 mg L^{-1}; May 2005) throughout the estuary. Ammonium (NH_4) concentrations were highly variable, and no spatial or temporal patterns were clearly evident. In contrast, concentrations of nitrite + nitrate (NO_2 + NO_3) were consistently highest in the riverine region of the estuary, where a peak value of 0.73 mg L^{-1} occurred at Danger Point in May 2005 (Table 2). Chlorophyll-*a* concentrations were highest in spring at the Collver Point and Valino Island sites, but the chlorophyll-*a* values were highest in summer in the riverine (Danger Point) region. During all sample periods, the concentration of chlorophyll-*a* was always greatest in the water column near the Valino Island study site, intermediate at the Collver Point site, and lowest at the Danger Point site (Table 2). Silica (SiO_2) concentrations were highly variable and ranged between 0.49 and 1.19 mg L^{-1} at Collver Point, between 1.02 and 2.93 mg L^{-1} at Valino Island, and between 0.007 and 2.92 mg L^{-1} at Danger Point.

Sediment Surface Elevations

Substantial changes in sediment surface elevations were observed within eelgrass beds at the Valino Island and Danger Point study sites (Figure 4). Several RSET stations were established in February 2005, and measurements recorded shortly after installation were used as the baselines for future assessments of changes in elevation of the surface sediments. Comparison of RSET measurements between the baseline conditions (February 2005) after a period of 6 months (August–September 2005) and after 12 months (February 2006) revealed accumulation of sediments at the North, East, and South compass bearings within the Valino Island eelgrass bed (Figure 4). In contrast, a loss of sediments was observed at all compass bearings within the Danger Point eelgrass bed (Figure 4). The rate of sediment accumulation averaged about 0.84 mm mo^{-1} at the three Valino Island RSET bearings. In contrast, the surface elevation decreased at a rate of about 0.44 mm mo^{-1} at the Danger Point study site. Installation of structural supports for a work platform created scour holes near the RSET station at the Collver Point study site and did not allow direct comparisons of sediment surface elevations in 2005 at this site.

Water Table Depths

The depth of the water table changed seasonally in a consistent manner within the salt marshes at all three study sites (Figure 5). Water table depths (measured relative to the marsh surface) were generally shallow during the wet season (February 2005) and increased during the dry season (July 2005) as the marshes dried out and the emergent vegetation reached the peak of biomass. The increase in water table depth was moderate in salt marshes located in the marine-dominated and polyhaline regions of the estuary and was much greater in the riverine/mesohaline region. For example, average water table depth increased from 17.8 cm to 23.6 cm (32%) at the Collver Point study site, increased from 5.5 cm to 7.2 cm (31%) at the Valino Island study site, and increased from 3.7 cm to 15.7 cm (324%) at the Danger Point study site (Figure 5). Pore-water salinities, measured within the groundwater wells, were generally lower than salinities measured within the adjacent tidal channels. These results indicate that substantial temporal and spatial fluctuations in groundwater can occur despite periodic inundation of the marshes by flooding tides, and that groundwater dynamics may serve a potentially important role in determination of

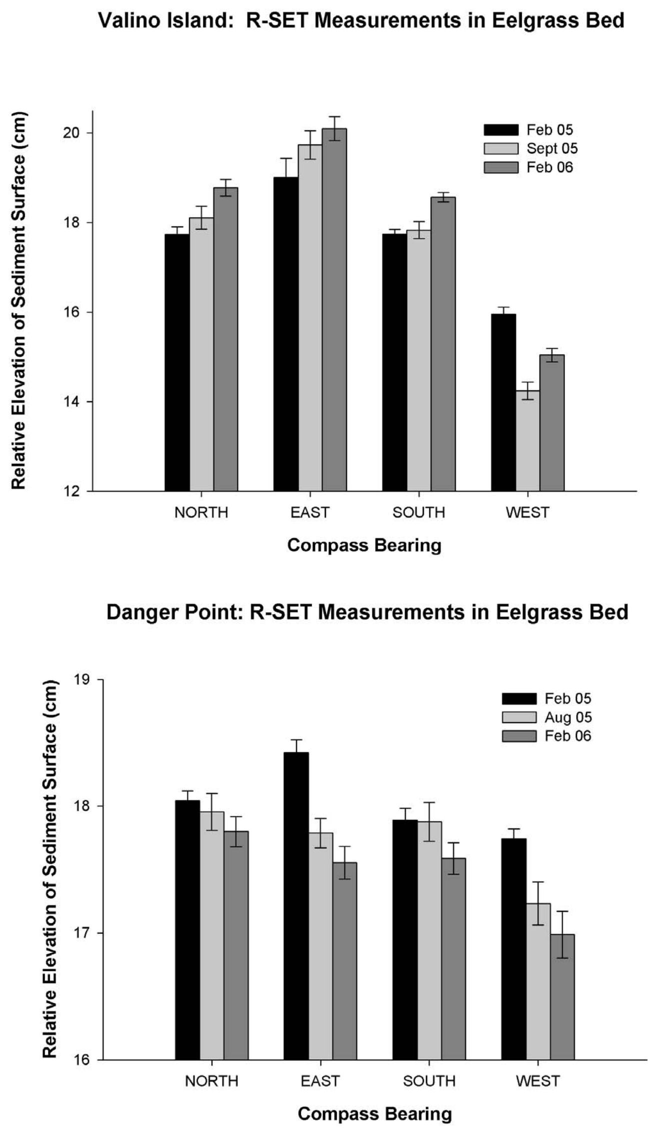

Figure 4. Changes in sediment surface elevations within eelgrass beds at the (A) Valino Island and (B) Danger Point study sites. Histograms indicate comparison of R-SET measurements between baseline conditions (February 2005) after a period of 6 mo (August–September 2005) and after 12 mo (February 2006). Histograms indicate mean surface elevation (cm) relative to anchor benchmark; error bars indicate standard error. Note increase in surface elevation at the North, East, and South compass bearings within the (A) Valino Island eelgrass bed and decrease in surface elevation at all compass bearings within the (B) Danger Point eelgrass bed.

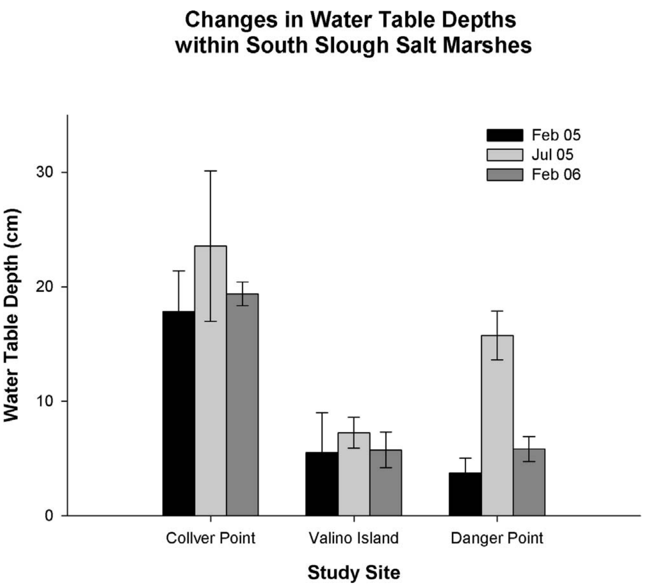

Figure 5. Changes in the depth to the water table relative to the marsh surface within the Collver Point, Valino Island, and Danger Point salt marshes. Histograms indicate mean distance (cm) below the marsh surface to the water table; error bars indicate standard error. Note the relatively shallow depth of the water table at all sites in February 2005 and February 2006 and the depth to the water table in July 2005.

the composition and growth of the salt marsh communities within the South Slough.

Salt Marshes

Communities of emergent salt marsh plants exhibited substantial spatial variability and seasonal differences along the estuarine gradient of the South Slough. For example, the greatest species richness of salt marsh plants was always observed at the Danger Point study site (Tables 3–5) within the riverine/mesohaline region of the estuary. The Collver Point and Valino Island salt marshes consistently exhibited lower and comparable species richness in the marine-dominated and polyhaline regions, respectively. Spatial differences were also observed in the diversity of the salt marsh communities. Simpson's Index and Shannon-Wiener Index values were generally high and similar for the Collver Point and Danger Point communities and were lower for the salt marsh community at Valino Island (Tables 3–5). Seasonal differences in the diversity of marsh plant communities were also evident, with the greatest diversity observed in the summer months (July and August) and lower diversity observed in winter (February; Tables 3–5). Each community was characterized by a group of four to seven dominant species (*i.e.,* plants that occurred at frequencies $>10\%$), which, together, established the overall ecological composition of the marsh (Tables 3–5). Species equitability values were consistently greatest for the Collver Point marsh community and indicate that the different species of salt marsh plants were distributed relatively evenly among the community. In contrast, species equitability values were consistently low for the Valino Island marsh,

Table 3. *Summary metrics and relative composition for dominant members of emergent salt marsh communities at three study sites located along the estuarine gradient of the South Slough, Oregon (July–August 2004). Species richness* (S) *values indicate maximum number of salt marsh plants observed within quadrats at the study site. The species of the most common marsh plants are shown as well as the percentage of the marsh community for each species at each study site.*

	Study Sites		
	Collver Point (Marine Dominated)	Valino Island (Polyhaline)	Danger Point (Riverine/ Mesohaline)
Community metrics			
No. of quadrats (n)	21	20	30
Species richness (S)	12	9	16
Simpson index (D)	8.76	4.41	8.58
Shannon-Wiener index (H)	3.21	2.43	3.31
Species equitability (E)	0.89	0.77	0.85
Salicornia virginica	19.54	32.76	5.63
Distichlis spicata	14.94	24.14	10.56
Triglochin maritimum	11.49	8.62	16.20
Jaumea carnosa	11.49	10.35	4.22
Carex lyngbyei	5.75	—	19.01
Deschampsia caespitosa	5.75	3.45	13.38
Cuscuta salina	16.09	3.45	—
Unvegetated mud	—	10.35	3.52
Agrostis stolonifera	—	—	11.27
Hordeum jubatum	6.90	—	—
Potentilla pacifica	—	—	5.63
Glaux maritimus	—	—	3.52
Totals	91.95	93.12	92.94

Table 4. *Summary metrics and relative composition for dominant members of emergent salt marsh communities at three study sites located along the estuarine gradient of the South Slough, Oregon (February 2005). Species richness* (S) *values indicate maximum number of salt marsh plants observed within quadrats at the study site. The species of the most common marsh plants are shown as well as the percentage of the marsh community for each species at each study site.*

	Study Sites		
	Collver Point (Marine Dominated)	Valino Island (Polyhaline)	Danger Point (Riverine/ Mesohaline)
Community metrics			
No. of quadrats (n)	21	20	30
Species richness (S)	7	8	11
Simpson index (D)	5.34	3.97	6.94
Shannon-Wiener index (H)	2.51	2.23	2.97
Species equitability (E)	0.89	0.79	0.86
Salicornia virginica	31.03	31.15	4.25
Distichlis spicata	17.24	22.95	11.34
Deschampsia caespitosa	12.07	3.28	16.50
Agrostis stolonifera	12.07	—	19.59
Unvegetated mud	5.17	21.31	—
Drift algae	15.52	8.20	—
Carex lyngbyei	—	—	23.71
Jaumea carnosa	—	8.20	—
Triglochin maritimum	—	—	6.19
Grindelia integrifolia	—	—	6.19
Trifolium wormskjoldii	—	—	5.15
Totals	93.10	95.09	92.92

Table 5. *Summary metrics and relative composition for dominant members of emergent salt marsh communities at three study sites located along the estuarine gradient of the South Slough, Oregon (July 2005). Species richness* (S) *values indicate maximum number of salt marsh plants observed within quadrats at the study site. The species of the most common marsh plants are shown as well as the percentage of the marsh community for each species at each study site.*

	Study Sites		
	Collver Point (Marine Dominated)	Valino Island (Polyhaline)	Danger Point Riverine/ Mesohaline)
Community metrics			
No. of quadrats (n)	20	20	28
Species richness (S)	10	11	14
Simpson index (D)	8.78	6.04	8.74
Shannon-Wiener index (H)	3.11	2.87	3.32
Species equitability (E)	0.94	0.83	0.87
Salicornia virginica	17.78	31.25	3.57
Triglochin maritimum	12.22	10.94	17.86
Distichlis spicata	13.33	17.19	10.00
Jaumea carnosa	11.11	10.94	2.14
Carex lyngbyei	4.44	—	18.57
Agrostis stolonifera	4.44	4.69	12.86
Deschampsia caespitosa	10.00	—	11.43
Cuscuta salina	13.33	6.25	—
Drift algae	10.00	9.38	—
Juncus effuses	—	—	6.43
Potentilla pacifica	—	—	5.00
Unvegetated mud	—	4.69	—
Glaux maritimus	—	—	3.57
Aster subspicatus	—	—	3.57
Grindelia integrifolia	—	—	2.14
Totals	96.65	95.33	97.14

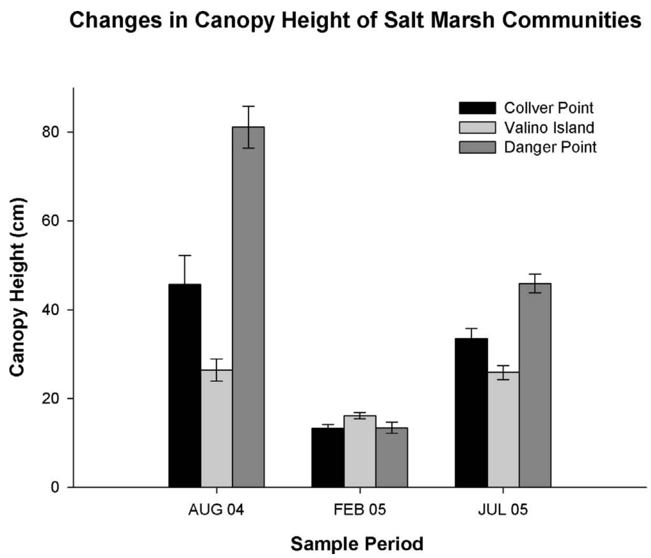

Figure 6. Changes in canopy height of salt marsh communities at three study sites within the South Slough estuary. Measurements of canopy height are pooled for all species of emergent vegetation for sampling periods in August 2004, February 2005, and July 2005. Histograms indicate mean canopy height (cm) above the marsh surface; error bars indicate standard error.

where the community was dominated by the abundance of pickleweed and saltgrass (Tables 3–5). The intermediate species equitability values observed within the Danger Point salt marsh indicate that the salt marsh community at this riverine site was strongly influenced by a group of four common salt-tolerant species, including seaside arrowgrass, Lyngbye's sedge, creeping bentgrass (*Agrostis stolonifera*), and saltgrass.

Spatial and temporal differences were also observed in the composition and abundance of plants that make up the salt marsh communities throughout the South Slough estuary. Pickleweed was the most abundant plant at the Collver Point and Valino Island study sites in all sampling periods, where the frequency of observations within study plots varied between 17% and 33% (Tables 3–5). Spatial cover values for *S. virginica* were typically between 47% cover (standard deviation [SD], 32%) and 49% cover (SD 25%) during the summer at Collver Point and between 49% cover (SD 35%) and 59% cover (SD 26%) at Valino Island. In contrast, the emergent marsh community was dominated by Lyngbye's sedge and seaside arrowgrass at the Danger Point study site (Tables 3–5). The frequency of observations for *C. lyngbyei* remained fairly constant (between 19% and 24%) at Danger Point, and the frequency of observations for *T. maritimum* varied seasonally between 16% and 18% in the summer and about 6% in the winter (Tables 3–5). Spatial cover values for *C. lyngbyei* were typically high (between 27% cover [SD 24%] and 40% cover [SD 34%]) throughout the year at the Danger Point study site.

The canopy height of emergent marsh plants changed throughout the year within all three of the study sites (Figure 6). Canopy heights were consistently greatest during summer (July and August) at the Danger Point site, where the plants reached maximum heights of 45 cm to 81 cm. Low canopy heights occur at all sites in winter (February), when the emergent marsh plants die back and persist primarily as woody stems and belowground roots. The high-summer canopy height values reflect domination of the Danger Point salt marsh by the perennial graminoids *Carex lyngbyei, Triglochin maritimum,* and *Deschampsia caespitosa* (Tables 3–5). In contrast, the lower summer canopy height values at the Collver Point and Valino Island salt marshes reflect domination by the mixture of perennial, low-growing graminoid (*Distichlis spicata*) and forb species (*Salicornia virginica*; Tables 3–5).

Eelgrass Beds

Temporal changes in the spatial cover and density of eelgrass (*Zostera marina*) were evident at all three study sites (Figure 7). The eelgrass beds reached their peak spatial cover in the summer months, and all of the beds died back, with reduced spatial cover values, in the winter. The eelgrass beds at Collver Point and Valino Island exhibited similar spatial cover and density patterns (Figure 7). The greatest numbers of small plants occurred at Collver Point and Valino Island in February 2005 and 2006, and lower densities of larger plants were observed in the summer of 2004 and 2005. In contrast, the eelgrass bed at Danger Point exhibited a dissim-

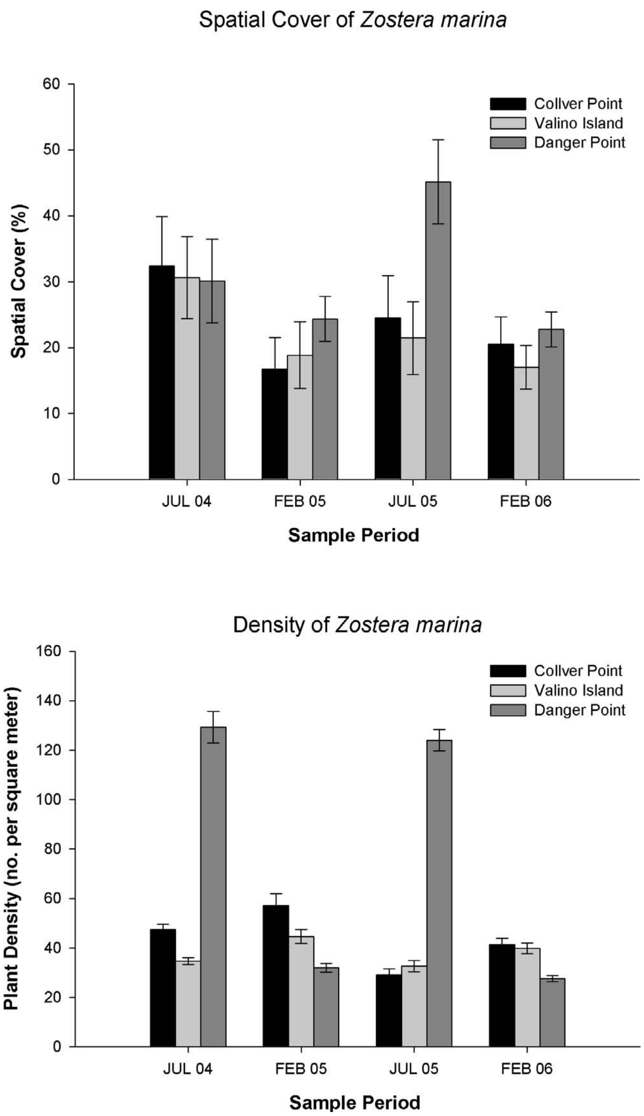

Figure 7. Changes in the spatial cover and density of *Zostera marina* measured along the NERR protocol transect lines (2004–06) at three study sites within the South Slough estuary. Histograms indicate mean; error bars indicate standard error.

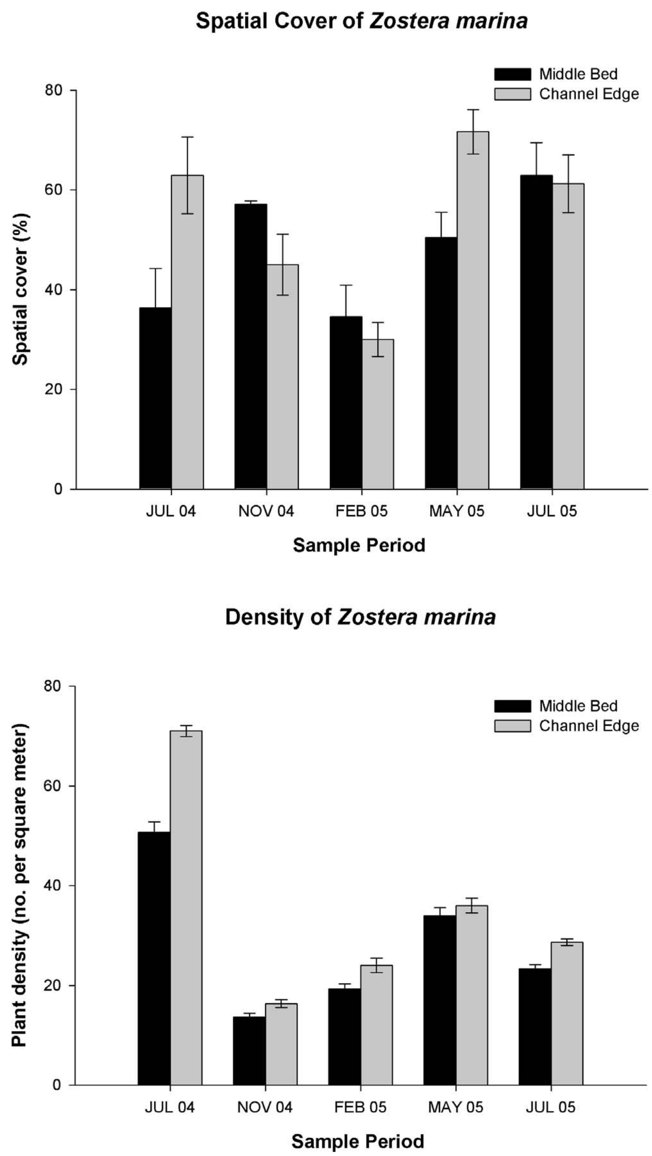

Figure 8. SeagrassNet sampling at Valino Island with changes in the spatial cover and density of *Zostera marina* along two of the SeagrassNet transect lines during 2004–05. See Figure 2 for location of SeagrassNet transects. Histograms indicate mean; error bars indicate standard error.

ilar density pattern with the greatest number of plants in July of 2004 and 2005 and lower densities in February 2005 and 2006 (Figure 7B). Blade lengths for the eelgrass plants were generally larger (>70 cm) at the Collver Point and Valino Island study sites, whereas blade lengths were substantially smaller (<42 cm) at the Danger Point site.

Additional data were collected to describe temporal changes over the period of 2004–05 in the spatial cover, density, and biomass of *Zostera marina* along two SeagrassNet transect lines established at the Valino Island study site (Figure 8). The spatial cover of *Z. marina* was greatest (>60% cover) in the spring and summer within the region of the eelgrass bed that occupies the lowest tidal elevation nearest the edge of the tidal channel, and the lowest spatial cover values (30%–35% cover) were observed in February 2005. Densities of *Z. marina* plants were also low in November 2004 and February 2005 within the lower and middle regions of the eelgrass bed (Figure 8B). This pattern contrasted with the high winter densities of *Z. marina* observed within the eelgrass bed at the upper intertidal zone at Valino Island (Figure 7B) and is consistent with low winter densities observed for *Z. marina* at Danger Point. Aboveground biomass of *Z. marina* plants was generally between 0.6 to 0.9 g dry weight per 0.0035 m^{-2} (170–260 g m^{-2}), and the lowest biomass values occurred in May 2005 in both the lower and middle regions of the Valino Island eelgrass bed. Aboveground biomass contributed about 75% of the total plant biomass in both regions of the eelgrass bed. The spatial cover of *Z. marina* plants was generally greater along the SeagrassNet transects in comparison to the transect lines sampled by the NERR protocol; however, the densities of *Z. marina* plants were not substantially different (Figures 7 and 8).

DISCUSSION

The South Slough estuary encompasses the full environmental gradient of marine, polyhaline, mesohaline, oligohaline/riverine, and tidal fresh hydrographic regimes that are integral components of tidal drainage basins in Pacific Northwest estuaries. At its northern (seaward) side, the mouth of the South Slough estuary merges with the Coos estuary near its confluence with the Pacific Ocean. Conversely, at its southern (landward) side, the riverine region of the estuary transitions from open salt marshes and freshwater ponds to forested wetlands, riparian areas, and coastal forests. Consequently, the South Slough estuary functions as a land-margin ecosystem that contains representative habitats and communities along the entire environmental gradient from the marine-dominated channels and tideflats, through the polyhaline and mesohaline estuarine mixing zone, to a mixture of estuarine, riparian, and upland habitats. The estuarine gradient within the South Slough provides an ideal environmental setting for concurrent monitoring of physical parameters (*i.e.,* water level, temperature, salinity, turbidity), dissolved nutrients (chlorophyll, nitrates, phosphate), and the dynamics of adjacent communities of salt marshes and eelgrass beds. We have previously established a series of long-term monitoring sites located within salt marshes, eelgrass beds, and tidal channels located along the estuarine gradient of the South Slough (CORNU and SADRO, 2002; POWELL and RUMRILL, 2001; RUMRILL and CORNU, 1995; THOM *et al.,* 2003) to provide time-series data on several physical and biotic indicators of estuarine ecological condition in a drowned river-mouth estuary that is representative of the lower Columbian biogeographic region (RUMRILL, 2006). However, the dynamics of adjacent salt marsh and eelgrass communities have not previously been assessed concurrently within any of the monitoring sites within the South Slough.

Salt marshes, eelgrass beds, and benthic macroalgae frequently occur adjacent to each other along the littoral margins of tidal channels within Pacific Northwest estuaries. These plant communities are of such ecological importance that they provide the primary forms of living habitat within the intertidal regions of the South Slough (RUMRILL, 2006). The lower intertidal community typically includes a mixed species assemblage of submerged aquatic vegetation (*i.e.,* native eelgrass [*Zostera marina*], dwarf eelgrass [*Zostera japonica*], and macroalgae *Ulva* spp. [*Enteromorpha prolifera, Chaetomorpha californica*]). The middle and high intertidal communities of emergent salt marsh vegetation are a diverse mixture of native species (*i.e., Carex lyngbyei, Salicornia virginica, Triglochin maritimum, Jaumea carnosa, Distichlis spicata, Deschampsia cespitosa,* and *Agrostis alba*) and nonindigenous species (*Cotula coronopifolia* and *Agrostis stolonifera*).

Native eelgrass (*Zostera marina*) is widely recognized to serve numerous important ecological functions in Pacific Northwest estuaries (PHILLIPS, 1984; SIMENSTAD, 1983). Meadows of *Z. marina* support diverse assemblages of infaunal and epifaunal invertebrates by several processes, including (1) by providing physical structure both aboveground and belowground in the shallow subtidal and intertidal flats, (2) by locally modifying tidal water flow and sediment deposition, (3) by enhancing nutrient exchange between sediments and the water column, and (4) by creating large quantities of organic matter that serve as living and detrital food sources for estuarine consumers (BACH, THAYER, and LACROIX, 1986; EDGAR, 1990; FONSECA and FISHER, 1986; FONSECA *et al.,* 1983; HARLIN, THORNE-MILLER, and BOOTHROYD, 1982; HEMMINGA, HARRISON, and VAN LENT, 1991; NIENHUIS and GROENENDIJK, 1986; ORTH and HECK, 1980; ORTH, HECK, and VAN MONTFRANS, 1984; PETERSON, SUMMERSON, and DUNCAN, 1984; PREGNALL, 1993; SIMENSTAD *et al.,* 1988). In addition, beds of *Z. marina* can also serve as nurseries and refuge areas for resident and migratory juvenile fishes, waterfowl, and invertebrates (PHILLIPS, 1984). Western black brant geese (*Branta bernicla nigricans*) have a winter diet that consists largely of eelgrass (COTTAM, LYNCH, and NELSON, 1944; COTTAM and MUNRO, 1954), and several other waterfowl, including greater scaup (*Aythya marila*), wigeon (*Anas penelope*), and teal (*Anas crecca*) also use eelgrass in their diets (COTTAM, LYNCH, and NELSON, 1944; TUBBS and TUBBS, 1983). SIMENSTAD and WISSMAR (1985) determined that eelgrass provides the fundamental basis of the food web for out-migrating juvenile chum salmon, and eelgrass also supports communities of preferred invertebrate prey items for juvenile chinook salmon in Pacific Northwest estuaries (SIMENSTAD, 1983; SIMENSTAD, FRESH, and SALO, 1982). In some estuaries, Pacific herring (*Clupea pallasi*) spawn on eelgrass, where the blades provide a substratum for development and aeration of the adherent egg masses (LEVINGS, 1990). Eelgrass meadows also function as hunting grounds or refuges from predation for juvenile and adult stages of other ecologically, recreationally, and commercially important finfish and shellfish species (FREDETTE *et al.,* 1990; SUMMERSON and PETERSON, 1984).

Emergent salt marshes occur throughout the South Slough as a distinct transitional ecotone located at the interface between the estuarine, freshwater, and terrestrial ecosystems. AKINS and JEFFERSON (1973) recognized eight distinct types of salt marshes in Oregon estuaries. Nearly all of these different types of marshes occur within the South Slough, and three are the subject of the present study. For example, the Danger Point salt marsh is representative of a mature, high marsh; the Collver Point marsh is characterized as a low, silty marsh; and the Valino Island marsh is a low, sandy marsh (AKINS and JEFFERSON, 1973). Local edaphic factors influence the composition and distribution of emergent marsh communities at these sites, including the time and duration of tidal inundation, surface and pore water salinity, soil permeability and aeration, soil type, nutrient availability, extent of peat development, air and water temperatures, drainage patterns, water table heights, precipitation, and exposure to incident light (GILMAN, 1993; RUMRILL, 2006). Several important ecological functions and services are provided by the salt marshes within the South Slough, including primary production of grasses and sedges (CORNU and SADRO, 2002; EWING and SEEBACHER, 1997; FRITZ, 2001) and seasonal contribution of the marsh plants into detritus food webs (SIMENSTAD, 1983). In addition, the salt marshes also provide resting and forage habitat for migratory birds, trap sediments and contribute to improvement of estuarine water quality, and accommodate the episodic flooding of tidal waters (BOULE and BIERLY, 1987; RUMRILL, 2006).

Within the South Slough, the plant communities that occur in salt marshes and eelgrass beds are locally dominated by relatively few species. Presumably, these estuarine plant communities share common resource requirements and physiological traits that allow them to tolerate ambient stresses imposed by the different hydrographic regions of the estuary. Although the species richness and biotic diversity of macrophytes within the adjacent salt marsh and eelgrass communities in the South Slough are relatively low, the genotypic and genetic diversity of these systems is unknown. Recent investigations of genetic diversity within beds of *Zostera marina* (OLSEN *et al.,* 2004; REUSCH and HUGHES, 2006) indicate that the diversity of nuclear recombinant DNA and several microsatellite loci can be substantial within single-species beds tested in temperate Atlantic and Pacific estuaries. In addition, HUGHES and STACHOWICZ (2004) found that *Z. marina* beds with high genetic diversity were correlated with higher plant densities in winter months and with enhanced use of pore water nutrients. They also exhibited elevated resistance to stress and destructive grazing by geese. Increased genetic diversity may also be linked with local adaptations to resist colonization by nonindigenous species and greater resource use in communities of salt marsh plants (PROFFITT *et al.,* 2005; TRAVIS and HESTER, 2005).

Information generated by the present study indicates that the adjacent salt marshes and eelgrass beds develop community characteristics within the South Slough that are strongly reflective of their location along the estuarine gradient. For example, the community composition, spatial cover, and density of macrophytes within the salt marsh and eelgrass communities were very similar between the Collver Point (marine-dominated) and Valino Island (polyhaline) study sites, where mean monthly salinities in the tidal channel ranged between 25 and 32 and water temperatures were moderate (10–16 °C) throughout the year. In contrast, the salt marsh communities and eelgrass beds were distinctly different at the Danger Point (riverine/mesohaline) study site, where mean monthly salinities ranged between 10 and 20 and water temperatures were much warmer in summer (20 °C) than in winter (9 °C). These intertidal salt marshes and eelgrass beds are highly productive and ecologically important components of the South Slough estuarine ecosystem despite their low richness of macrophyte species and relatively low metrics of community diversity (BORDE, *et al.,* 2003; HEMMIGA and DUARTE, 2000; THOM *et al.,* 2003; TRAVIS and HESTER, 2005). Low species richness and community diversity within these intertidal communities are contradictory to the widespread understanding that species diversity is positively correlated with enhanced ecosystem functions (LOREAU *et al.,* 2001; REUSCH and HUGHES, 2006).

Investigation of the adjacent salt marsh and eelgrass communities is also needed to gain a more complete understanding of the relationships between ecological functions (such as the timing of peak biomass, production of organic material and detritus, trapping of sediments, provision of forage and nursery areas, *etc.*) and macrophyte species richness, community composition and structure, and genetic diversity. Additional studies are also required to determine the ecological role of the estuarine gradient in determining spatial and temporal differences in primary production, nutrient cycling, and utility of the marsh and eelgrass communities by resident and migratory invertebrates, fish, and shorebirds. Concurrent assessment of the adjacent salt marshes, eelgrass beds, and water column conditions reported here represents an initial step toward development of an integrated approach to evaluation of the ecological status of the South Slough estuary that can incorporate descriptive information from multiple habitats and communities.

ACKNOWLEDGMENTS

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