The Ecology of the South Slough Estuary:

Site Profile of the South Slough National Estuarine Research Reserve

Steven S. Rumrill
South Slough National Estuarine Research Reserve
Charleston, Oregon

Oregon
Department
of State Lands

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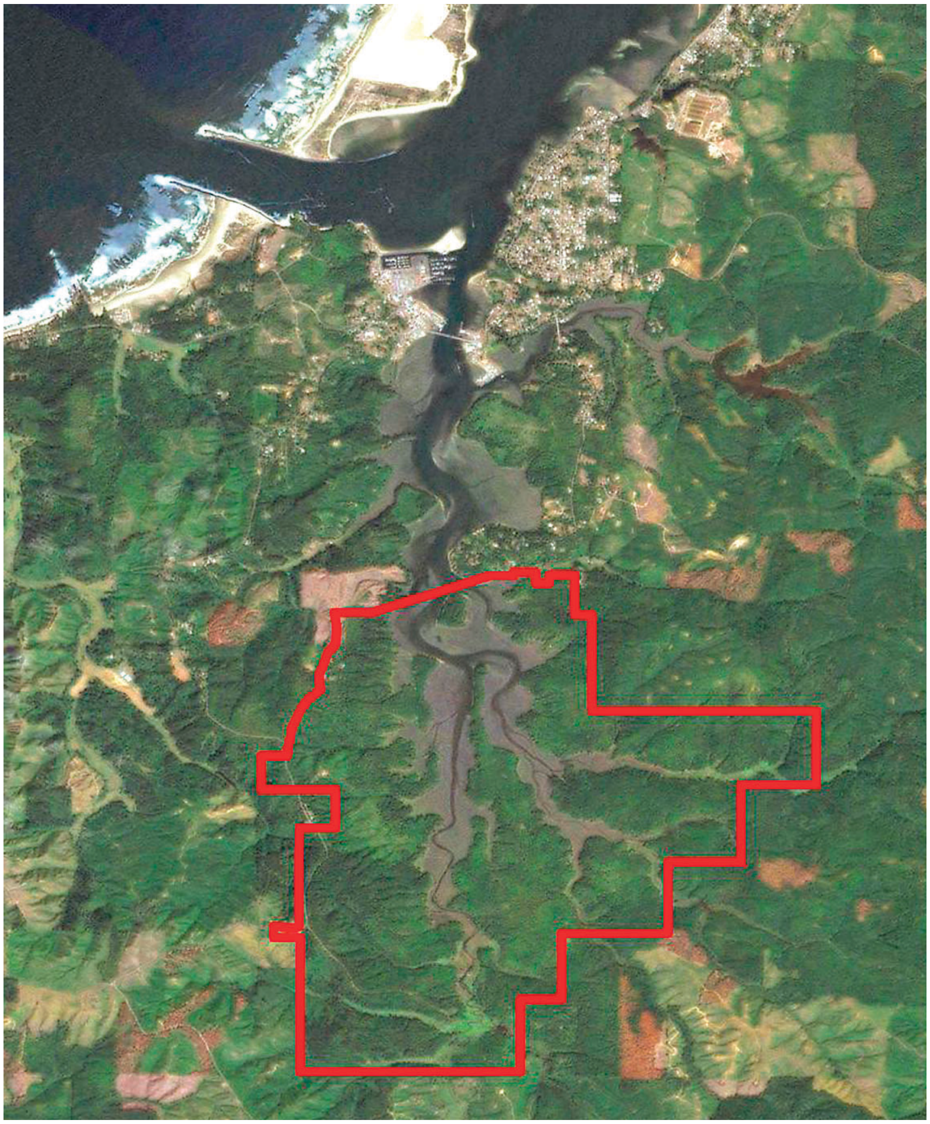

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THE ECOLOGY OF THE SOUTH SLOUGH ESTUARY, OREGON:

SITE PROFILE OF A NATIONAL ESTUARINE RESEARCH RESERVE

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CHAPTER 3. ESTUARINE HABITATS AND COMMUNITIES

CHAPTER 4. RIPARIAN COMMUNITIES AND UPLAND HABITATS

CHAPTER 5. ADAPTIVE MANAGEMENT OF THE SOUTH SLOUGH ESTUARINE ECOSYSTEM

FIGURE HEADINGS

Chapter 1

Chapter 2

Figure

Chapter 3

Chapter 4

Chapter 5

TABLE HEADINGS

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Table

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PREFACE

The South Slough estuary is an integral sub-unit of the Coos estuary, the largest and commercially most important shipping port on the Oregon coast. As a distinctive Pacific northwest coastal land-margin ecosystem, the South Slough watershed and estuary hold special regional importance as a series of linked terrestrial and estuarine habitats, and the ecotones support many species of plants, invertebrates, fishes, birds, and mammals. The natural resource values of the South Slough also attract recreational users, and the quiet tidal waters offer a readily accessible avenue for study and appreciation as well as opportunities for continued education and public outreach. The South Slough National Estuarine Research Reserve (NERR) provides an ideal ecological benchmark for fundamental and applied science investigations of ecological processes that occur within a relatively undisturbed estuarine tidal basin located in close proximity to a major shipping port. This Site Profile of the South Slough Estuary provides a summary and synthesis of existing scientific information and original datasets to present an overview for several key topics including: (1) an introduction to the South Slough watershed and estuary within the context of the lower Columbia biogeographic region; (2) descriptions of the geological framework, climate, hydrologic processes, and physical-chemical aspects of the estuarine environment; (3) the diversity of natural habitats, biotic communities, and their ecological relationships within the South Slough estuary; (4) descriptions of the composition and status of riparian habitats and upland forests within the South Slough NERR; and (5) a conceptual framework for adaptive estuarine and coastal management, monitoring, and future research. A significant portion of the South Slough estuary is afforded long-term protection by the South Slough National Estuarine Research Reserve. Key management issues for this coastal land-margin ecosystem include assessment of the cumulative effects of shoreline habitat loss and alteration, bioinvasions of the estuary by non-indigenous species, chronic degradation of estuarine water quality by non-point source pollutants, and threats of hazardous materials spills in the adjacent shipping port and nearshore Pacific Ocean.

The South Slough estuary provides support for a variety of living resources, critical physical processes, and essential ecological functions. The estuarine tidal channels and mudflats are of special importance to populations of resident and migratory shorebirds, waterfowl and raptors, and they sustain productive sites for commercial and recreational shellfish harvests, aquaculture operations, and communities of estuarine and anadromous fish. Critical physical processes and essential ecological functions carried out within the South Slough estuary include stormwater management and flood control, trapping of sediments and non-point source pollutants by salt marshes and eelgrass beds, and the provision of nesting and forage areas for birds, fish, and marine mammals. The South Slough estuary also provides nursery sites and transitional zones for juvenile crabs, shrimp, bottom fish, and young salmon, and the shallow tidal basin is a productive source of suspended nutrients, organic materials, and detritus for filter-feeding and deposit-feeding invertebrates including several species of burrowing bivalves, shrimp, and polychaete worms. The strong physical gradient between marine and freshwater habitats encompassed by the South Slough estuary exerts a profound impact on the species composition and distribution of plants and animals that inhabit the tidal channels, mud and sandflats, and salt marshes.

Chapter 1

Introduction to the South Slough Estuary

1.1 Coastal Components of the Lower Columbia Bioregion

The Lower Columbia Biogeographic region is a particularly distinctive section of the Pacific northwest coast that spans the nearshore waters and estuaries from the mouth of the Columbia River (Astoria, OR) to Cape Mendocino (CA). The Lower Columbia (or middle Pacific / Columbian) Bioregion is defined as the portion of the Pacific northwest coastline that is under the seasonal influence of freshwater discharge from the Columbia River (FR 58:134, 1993). This 725 km stretch of coast extends over 5.5° of latitude (from 40.5°N to 46°N) and is an area of extraordinary ecological complexity and spectacular habitat diversity (Figure 1.1). Located between the subpolar communities of the Aleutian - West Coast Fjords Biogeographic Province (at the southern end of their distribution) and the subtropical communities of the Montereyan Biogeographic Province (at the northern end of their distribution), the Lower Columbia Bioregion is an important temperate zoogeographic transition zone for many marine and coastal species (Fager and McGowan, 1963; Croom *et al.,* 1995). Variability in the composition and characteristics of local habitats and biotic communities is considerable, and many features of the Lower Columbia Bioregion are dominated by the geomorphology of the continental coastline and the physical oceanographic conditions that distinguish the area as a significant sub-unit of the California Current Large Marine Ecosystem (Sherman, 1994; Simenstad *et al.,* 1997).

The Lower Columbia Bioregion is an integral component of the greater Pacific northwest / eastern boundary current ecosystem. Physical and biotic elements of this highly dynamic ocean circulation system exhibit inherent stability and variability across a wide range of spatial and temporal scales (Greenland, 1998). Numerous atmospheric, oceanic,

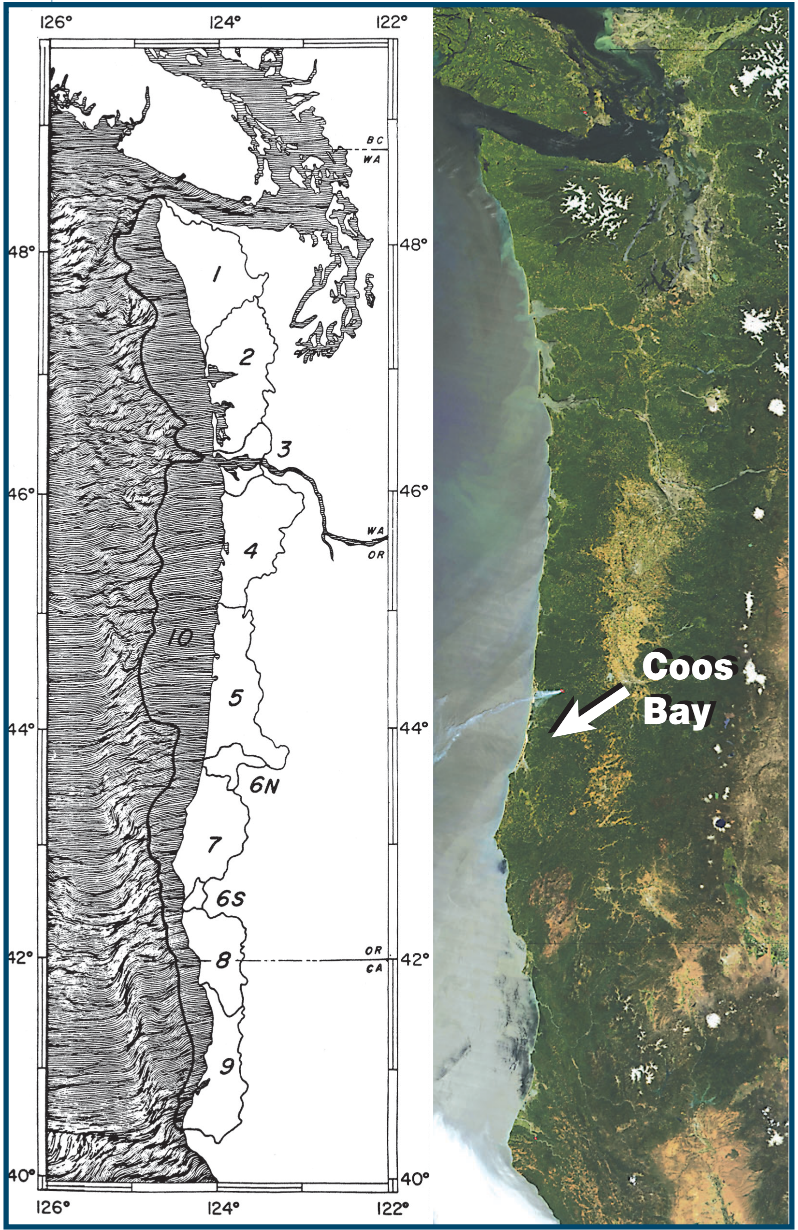


Figure 1.1. Pacific Northwest/Columbia Bioregion. Numbers indicate coastal region watershed units; 1 Olympia Rainforest, 2 Willapa-Grays Harbor, 3 Columbia Estuary, 4 Oregon North Coast, 5 Oregon Mid Coast, 6 Lower Umpqua & Lower Rogue, 7 Coos-Coquille, 8 Oregon/California Border, 9 Redwood Coast. Note that unit 10, the Continental Shelf, is not a watershed unit as such, but is a distinct marine portion of the Columbia Bioregion. Adapted from Proctor *et al.* 1980.

hydrologic, and ecological processes intersect at the eastern edge of the Pacific Ocean basin where the eastward-flowing Sub-Arctic Current encounters the north American continent. As the Sub-Arctic Current approaches north America, it enters a transitional domain where the current divides to form two distinct coastal waterways (Figure 1.2): (a) the northward-flowing Alaska Current, and (b) the southward-flowing California Current (Dodimead *et al.,* 1963; Hickey, 1989; Pearcy, 1992). Location of the transitional domain varies on a seasonal scale between 45°N in the winter and 50°N in the summer (Pickard and Emery, 1990). Bifurcation of the northward Alaska Current and southward California Current also varies on a decadal scale and is strongly related to the intensity of atmospheric forcing within the Arctic low pressure zone (Salmon, 1997). The California Current (an eastern Pacific Ocean boundary current) is driven primarily to the south along the continental slope by northerly winds, and the southward flow is interrupted seasonally along the continental shelf by wind-driven counter currents. Nearshore elements of the California Current and its associated countercurrents form a complex marine-terrestrial ecotone throughout the Lower Columbia Bioregion where water masses from the Pacific Ocean basin are mixed with freshwater discharged from the Columbia River and numerous smaller coastal watersheds.

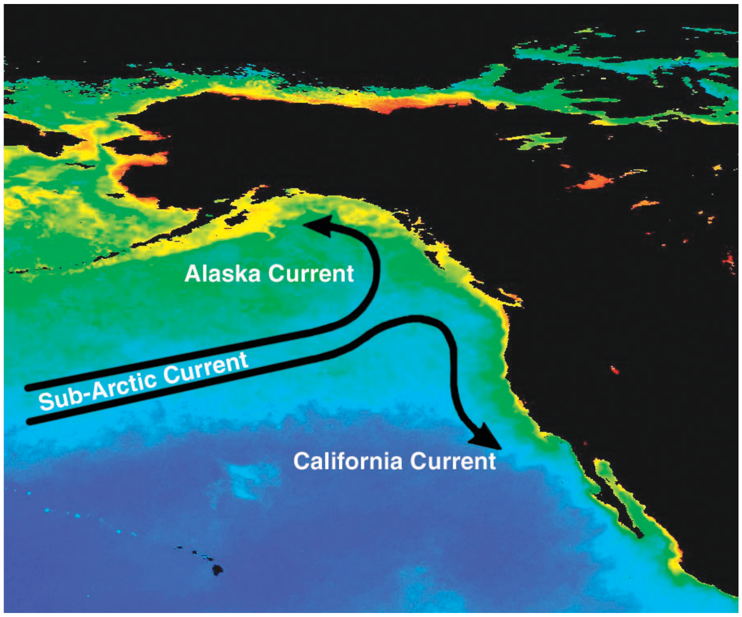


Figure 1.2. Bifurcation of the Sub-Arctic Boundary Current into the northward Alaska Current and southward California Current. The transitional domain for current divergence typically occurs immediately north of the Lower Columbia Bioregion. NASA/SeaWifs image shows high annual chlorophyl concentrations (yellow) along the coastline for 2000.

Several important factors influence marine and estuarine biotic productivity within the Lower Columbia Bioregion. These factors include: (a) latitudinal gradients in the strength of coastal upwelling, (b) timing and magnitude of discharges from the Columbia River, (c) coherence, integrity, and mixing within the Columbia River Plume, (d) geomorphology of the continental shelf and physiography of the coastline (including the location of headlands and linear stretches of sand), (e) rugged coastal range topography, steep coastal watersheds, and limited availability of estuarine habitats and embayments, and (f) biogeographic affinities in the distribution of species with northern and southern centers of distribution. Other important factors include interannual and decadal variability in separation of the Alaska and California Currents, and distinct seasonal differences between winter and summer nearshore current regimes. In addition, the nearshore ocean surface develops highly dynamic flow formations along the coasts of Oregon and northern California including coastal eddies, offshore jets, and meandering flow filaments that are superimposed on the generally slow southward flow of the California Current (Figure 1.3). Regional meteorological conditions and nearshore oceanic processes are frequently disrupted throughout the Lower Columbia Bioregion by El Niño - Southern Oscillation (ENSO) events and coastal ocean regime shifts that are linked to Pacific basin-wide processes and changes in the global atmosphere (Huyer and Smith, 1985; Greenland, 1998).

Seasonal discharge of snowmelt and rainwater from the Columbia River are prominent events that can greatly influence regional ocean conditions across the continental margin (Landry *et al.,* 1989; Bottom *et al.,* 1998). Discharge from the Columbia River averages 5,500 m^3s^{-1} (195,000 cubic feet per second) throughout the year, and dam-controlled outflows typically range from 3,000 to 17,000 m^3s^{-1} (Simenstad *et al.,* 1997). Freshwater from the Columbia River mixes slowly with ocean surface waters and forms a large dilute lens or "plume" that extends north to Vancouver Island in winter months and southwesterly from Astoria along the coast of Oregon to northern California in the summer (Figure 1.4). A strong narrow current sometimes develops along the boundary between the lighter river water and the dense saline ocean

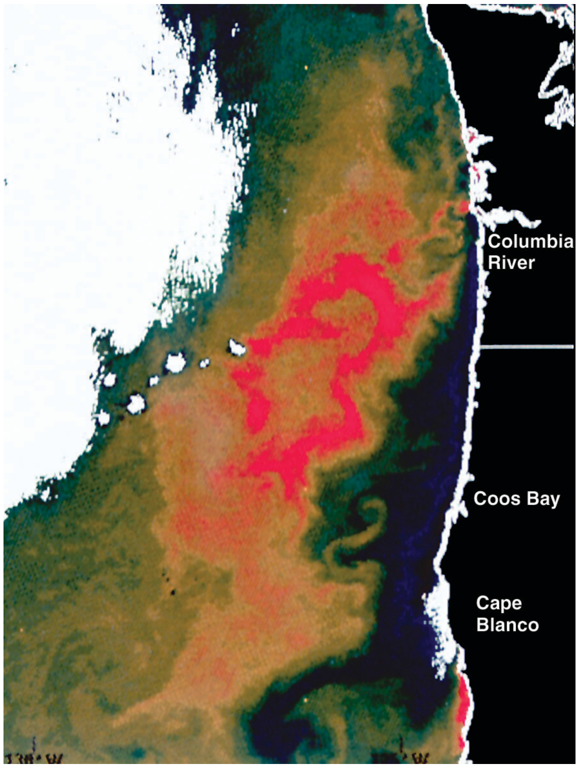


Figure 1.3. Remote sensing image of coastal upwelling and thermal jet formation at Cape Blanco, OR. The dark blue strip along the Oregon coast between theColumbia River and Cape Blanco indicates cold nutrient-rich ocean water brought to the surface by upwelling. Note strong upwelling off Coos Bay, and formation of an offshore thermal jet south of Cape Blanco. Adapted from NOAA – CoastWatch.

water. On the inshore side of the Columbia River Plume, the boundary current can enhance and strengthen the coastal jet, and the current functions as a partial barrier to offshore movement of surface water during upwelling (Huyer, 1983). Changes in wind direction force the Columbia River Plume and boundary current either closer or further away from the coast; winds from the south move the plume and current offshore, while north winds move them closer to shore.

The Columbia River contributes between 60% (winter) and 90% (summer) of the freshwater released into the nearshore surface waters between Cape Flattery (WA) and San Francisco Bay (CA) (Barnes *et al.,* 1972; Sherwood *et al.*, 1990; Simenstad *et al.,* 1992). Seasonal impoundment of Columbia River outflows behind dams and reservoirs in the summer followed by releases during winter has altered nearshore sea surface salinities from California to Alaska (Ebbesmeyer and Tangborn, 1992). Average surface salinities have decreased by 1.0 practical salinity units (psu) along the Washington coast and increased by 0.6 psu throughout the Lower Columbia Bioregion over the past 60 years. In some years, the low salinity surface waters of the Columbia River Plume (24-27 psu) represent an offshore extension of the Columbia River estuary that is strongly evident between distances of 5 and 40 miles offshore from Coos Bay, OR (Figure 1.4).

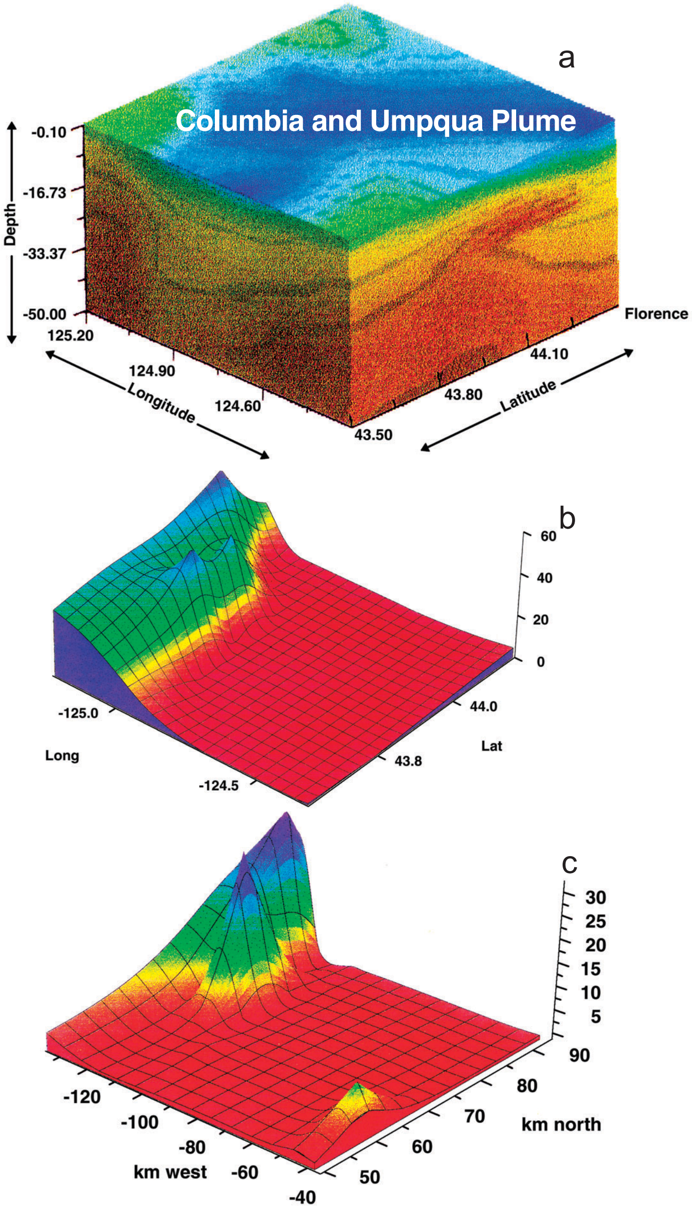
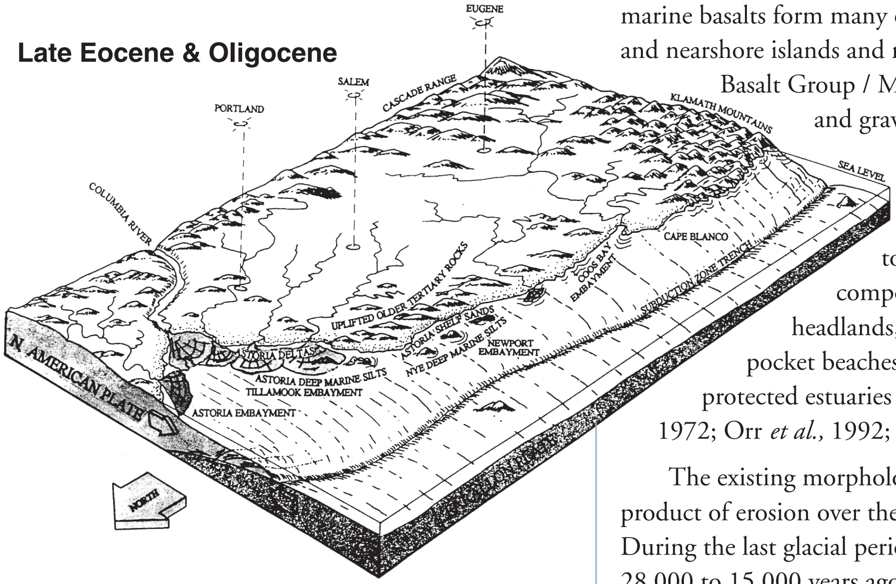


Figure 1.4. Diagrammatic section of the nearshore Pacific Ocean between Coos Bay and Florence, OR. Diagram (a) illustrates salinity isohalines and the broad shallow lens of low salinity surface water associated with the Columbia and Umpqua River Plumes; (b) shows high densities of myctophid fish seaward of the plume lens; and (c) shows peak densities of decapod zoea larvae seaward and shoreward of the plume lens.

1.1.1 Geological Setting

The coastline within the Lower Columbian Bioregion is mountainous with steep sloping cliffs, coast range watersheds, rocky headlands, and dune formations that drop directly into the sea. The geological setting of the bioregion is characterized by several formations of uplifted sedimentary mudstones and sandstones (generally Miocene: 15-24 Ma to Eocene: 38-55 Ma; million years old) along with younger Pleistocene marine terraces and sand dunes (0.1 to 1.5 Ma). These sedimentary materials were deposited on the seafloor during transgressional periods of elevated sea level (Figure 1.5). Older marine basalts form many of the headlands, outcrops, and nearshore islands and reefs (Columbia River Basalt Group / Miocene: 30-35 Ma). Sand and gravel eroded from the resistant rocks by the forces of wind, rain, and ocean waves contribute to the diverse shoreline composed of a mixture of rocky headlands, cobbly fields, coves, pocket beaches, open sandy beaches, and protected estuaries and tideflats (Dolan *et al.,* 1972; Orr *et al.,* 1992; Komar, 1998).


Late Eocene & Oligocene

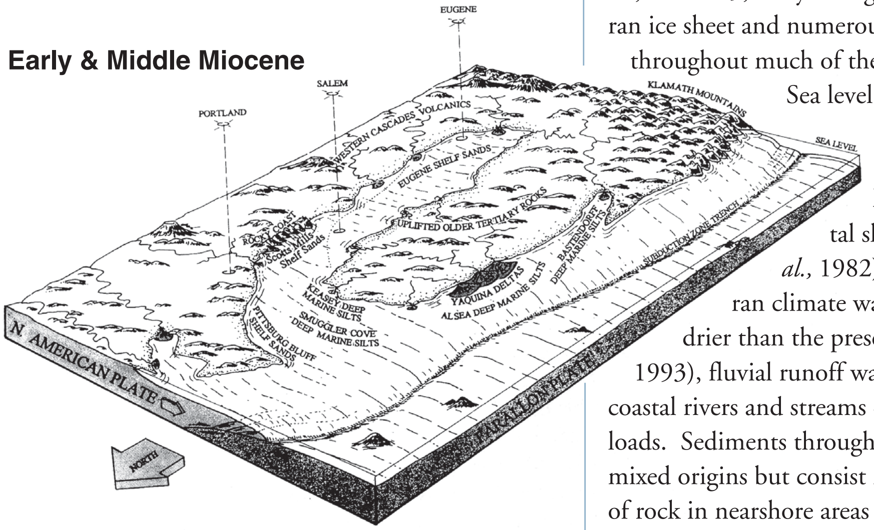

Early & Middle Miocene

Figure 1.5. Tertiary marine landscape of the Oregon shoreline in the late Eocene and Oligocene (40-26 mya), and in the early and middle Miocene (26-10 mya). Note the formation of the Bastendorff shales and deep marine silts within the Coos Bay embayment. Adapted from Orr and Orr, 1999.

The existing morphology of the coastline is the product of erosion over the last 5 million years. During the last glacial period (late Pleistocene: 28,000 to 15,000 years ago) the expansive Cordilleran ice sheet and numerous glaciers extended throughout much of the Pacific northwest region. Sea level was about 100 m below its present elevation during the regressional period, and large areas of the continental shelf were exposed (Porter *et al.,* 1982). Although the Cordilleran climate was significantly colder and drier than the present (Thompson *et al.,* 1993), fluvial runoff was probably high and the coastal rivers and streams carried large sediment loads. Sediments throughout the coastal zone have mixed origins but consist mostly of sand with pockets of rock in nearshore areas with subtidal rock, gravel, and muddy sand offshore. The continental shelf is a gently sloping submarine terrace that increases in depth from about 110 m at a distance of 9 km offshore to a depth of 1,830 m at the shelf break (80 km offshore). The shelf is narrow, averaging less than 52 km wide and extending only 64 km offshore at its widest point at Tillamook Head (OR). The shelf is narrowest near Cape Blanco, OR (28 km) and Cape Mendocino, CA (16 km).

The rugged mountainous coastline found throughout the Lower Columbia Bioregion was formed by tectonic processes associated with offshore interactions between the Juan de Fuca, Gorda, and

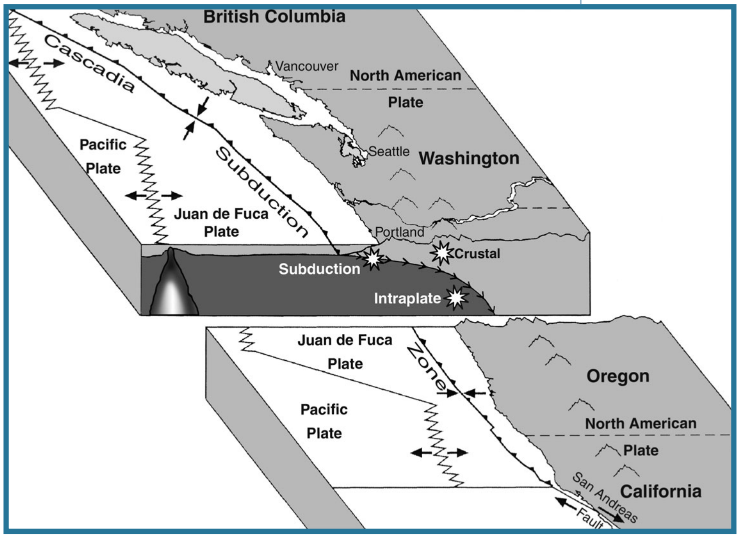


Figure 1.6. Seafloor spreading at the Pacific Plate drives the Juan de Fuca Plate beneath the North American Plate along the Cascadia Subduction Zone. Subduction along the coastal margin contributes to intraplate volcanic activity and regional tectonic uplift. Tectonic convergence along the Cascadia Subduction Zone also contributes to local compression of sedimentary materials within the South Slough, OR.

North America plates (Figure 1.6). New crustal rock originates at spreading ridges between the plates, and old oceanic rocks move laterally to the submarine trench where they slide beneath the North American plate (Proctor *et al.,* 1980). Oceanic rocks are heated under great pressure within the Cascadia subduction zone, and molten rock rises to the surface as magma within the series of Cascade volcanoes (*i.e.,* Mt. Ranier, Mt. Saint Helens, Mt. Hood, Mt. Shasta, Mt. Lassen). Pressure generated at the spreading ridges bounding the Juan de Fuca and Gorda plates is diminished somewhat by the formation of rifts and minor rearrangement of plates within the Blanco Fracture Zone. Although lateral movement of the seafloor bed occurs in an eastward direction at a rate of about 5.8 cm per year, ocean crust collides with the North American continent at a rate of only 2.5 cm per year due to the oblique angle of crustal subduction (Atwater, 1970; Komar, 1998). The Cascadia subduction zone off the Pacific northwest coast continues to be an area of high seismic potential. Long-term coastal uplift has been offset by short-term subsidence during large episodic earthquakes. These counteractive forces, combined with long-term sea-level rise, coastal erosion, and fluvial dynamics, are the most significant processes responsible for the present physiography of the coast (Proctor *et al.,* 1980).

Along with erosion of beaches and coastal cliffs, landslides, and river floods (Komar, 1998), inundation of the shoreline by episodic coastal subsidence, tsunamis, and soil liquefaction are serious potential hazards to coastal communities throughout the Lower Columbia Bioregion (Yeats, 1998). The entire Pacific northwest coast has a long prehistoric record of infrequent but catastrophic failures (Atwater, 1987; Darienzo and Peterson, 1990; Clarke and Carver, 1992). For example, tectonic slip along the Cascadia subduction zone (a 1,000 km long thrust fault that separates the Juan de Fuca and North America plates, Figure 1.6) has generated 11 great (magnitude 8) earthquakes during the past 6,000 years (Atwater and Hemphill-Haley, 1997; Kelsey *et al.,* 2002). The most recent great earthquake, of at least magnitude 9, probably ruptured much of the plate boundary along the Columbian Bioregion from Tolfino (Vancouver Island, BC) to Humboldt Bay (CA) about 300 years ago (probably 26 January 1700 AD; Satake *et al.,* 1996; Clague, 1997). Coastal areas subsided as much as 2 m during the earthquake, which was followed shortly by a devastating tsunami (Atwater *et al.,* 1991; Clarke and Carver, 1992; Nelson *et al.,* 1996). In response to the subsidence earthquake, the ground shook severely for several minutes along the western parts of British Columbia, Washington, Oregon, and northern California. Corroborative evidence of regional coastal subsidence, tsunami deposition, and sediment liquefaction has been gathered from late Quaternary deposits at several different locations within estuaries and along the coast (Atwater, 1987; Grant *et al.,* 1989; Peterson and Darienzo, 1991).

Several prominent submarine banks occur along the length of the continental shelf. The four major submarine features are the Nehalem Banks (45°42'N), Stonewall Banks (44°33'N), Heceta Banks (44°07'N), and Coquille Banks (43°04'N). The Mendocino Submarine Ridge (fracture zone) marks the southern end of the Lower Columbia Bioregion. Submerged rocky outcrops are found on the inner shelf, especially between Coos Bay and the

Table 1.1. The principal suppliers of sand to the Pacific northwest coast are the Columbia River, the Coast Range, and the Klamath Mountains. Each source supplies different heavy minerals to the beach and estuarine sands, and this makes it possible toassess their respective contributions (adapted from Klemens and Komar, 1988).

	Sand Composition												
Source	Augite	Diopside	Enstitite	Epidote	Hornblende, brown	Hornblende, green	Hypersthene	Garnet, clear	Garnet, pink	Glaucophane	Olivine	Staurolite	Zircon
Columbia River	19%		4%		9%	14%	45%	2%					2%
Coast Range	X				X								
Klamath Mountains	X	X		X	X	X	X		X	X	X	X	X

Rogue River, while sea stacks and rocky islands are exposed above the sea surface close to shore. Three prominent submarine canyons and numerous smaller submarine valleys cut through the outer edge of the continental shelf and the upper sections of the continental slope. First, the Astoria Canyon cuts deeply into the outer continental shelf about 16 km west of the Columbia River mouth. Second, the smaller Rogue Canyon traverses the continental shelf offshore of the Rogue River near Gold Beach (OR). Third, the Mendocino Canyon cuts through the continental shelf immediately north of the Mendocino Submarine Ridge (CA). These submarine canyons and valleys are important avenues for the transport of sediment across the shelf and down to the deep ocean floor (Komar, 1998).

The Columbia River contributes approximately 9.7 million metric tons of sediment per year to the lower Columbia basin, estuarine channels, and the adjoining continental shelf (Simenstad *et al.,* 1990). Additional sediments derive from several sources including smaller coastal rivers, the Strait of Juan de Fuca, and erosion from local cliffs and headlands (Strickland and Chasan, 1989). Distinctive sands from the Klamath Mountains were historically swept northward about 20,000 years ago during the regressional period of lower sea level (Scheidegger *et al.,* 1971). Mixtures of sand and mud from southern and northern sources are found along most of the continental margin (Table 1.1). Recent movement and redistribution of coastal sediments occurs largely within a series of littoral circulation cells that are separated by rocky promontories and headlands. Subtidal portions of the headlands extend into water sufficiently deep to prevent significant alongshore migration of sand (Komar, 1998). Physical and biotic factors that govern redistribution of coastal sediments within the littoral cells include river discharge, wave exposure and erosion, estuarine circulation patterns, bioturbation by burrowing organisms, and ocean dumping of material dredged from coastal harbors. In the winter, storms can resuspend the bottom sediments and redistribute materials across significant portions of the continental shelf (Komar, 1998).

1.1.2 Coastal Climate, Ocean Currents and Upwelling

Climatic conditions within the Lower Columbian Bioregion are dominated by the Pacific Ocean, and seasonally modulated offshore winds influence local temperature and rainfall patterns. Strong southwest winds during the late fall and winter bring large ocean swells, heavy rains and moisture inland from the Pacific Ocean, creating a cool, wet climate (Figure 1.7). During the spring transition period (typically April-May) the offshore winds switch directions and blow predominantly from the northwest through the summer and early fall. These northerly winds typically contribute to

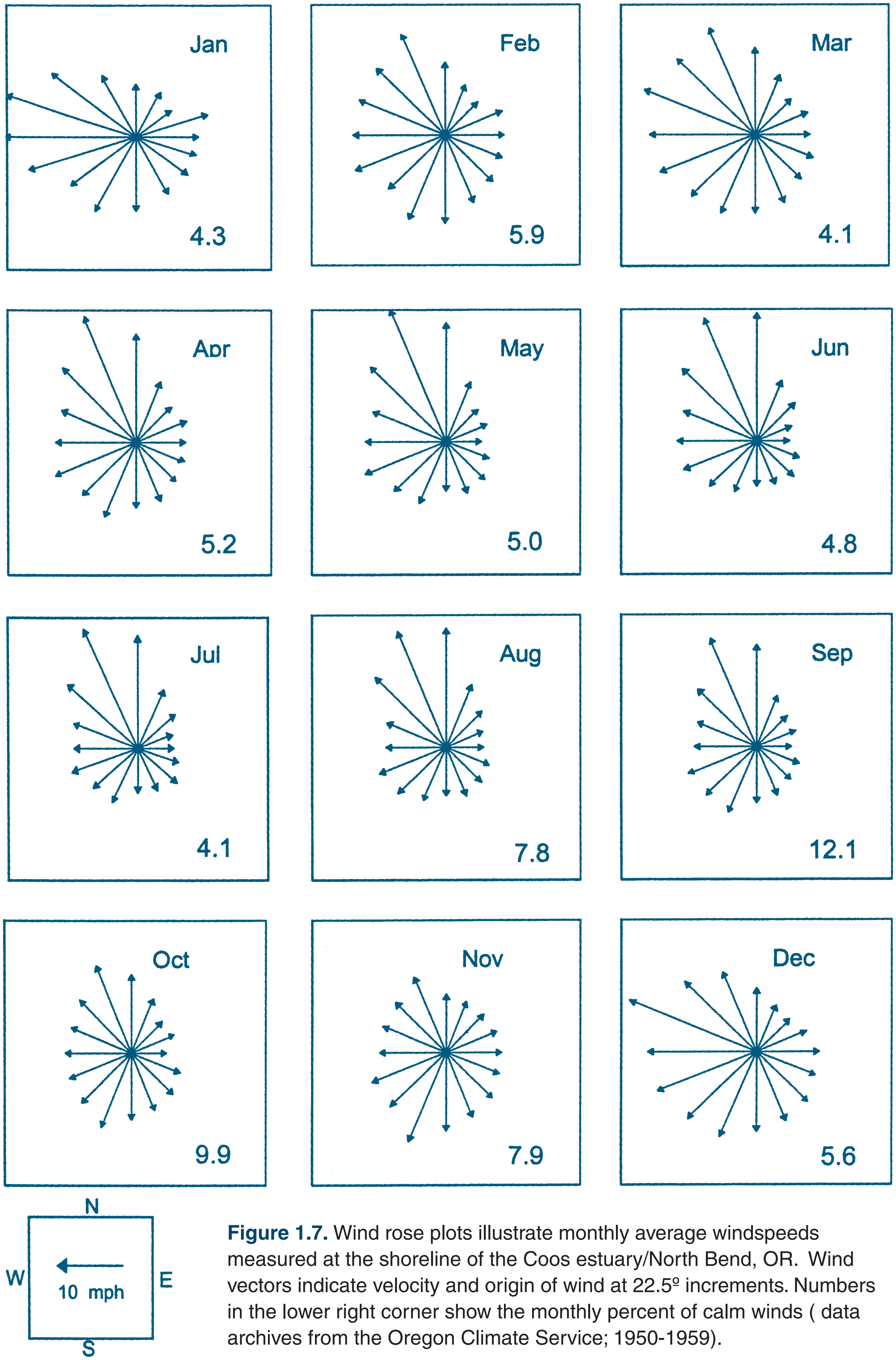


Figure 1.7. Wind rose plots illustrate monthly average windspeeds measured at the shoreline of the Coos estuary/North Bend, OR. Wind vectors indicate velocity and origin of wind at 22.5º increments. Numbers in the lower right corner show the monthly percent of calm winds (data archives from the Oregon Climate Service; 1950-1959).

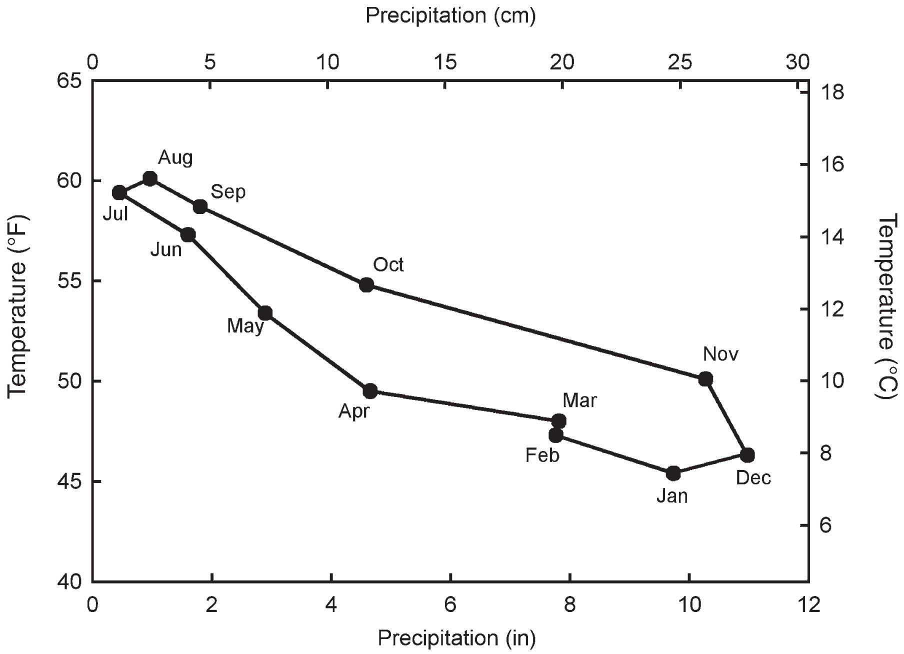


Figure 1.8. Long-term average monthly temperature and precipitation cycle in the immediate vicinity of the Coos estuary, OR. Air temperature and rainfall records are from the North Bend, OR airport meteorological station (1961-90).

4-5 major upwelling events where cold oceanic waters enrich the surface with nutrients, increase chlorophyll and phytoplankton concentrations, and support large populations of fish, invertebrates, seabirds and other animals. Wind-induced upwelling can lower nearshore sea surface temperatures to 6-8 °C and produce dense coastal fog in the summer (Proctor *et al.,* 1980). Coastal air temperatures throughout the Lower Columbian Bioregion range seasonally from 5-12 °C in January to 10-19 °C in August, while maximum temperatures exceed 35 °C and minimum temperatures rarely drop below 5 °C (Schultz, 1990). Local temperatures measured at the shoreline of the Coos estuary (North Bend, OR) follow a similar pattern with minimal temperatures of 7-8 °C in January and maximum temperatures of 14-16 °C in July and August (Figure 1.8). The westerly ocean winds move air masses over the Pacific Ocean where they exchange heat and become nearly saturated with moisture. As the Pacific air masses reach the North American continent they rise, cool, and release water in the form of fog, rainfall, and occasional snow. Most of the precipitation occurs during the winter months (November-March), and annual rainfall averages over 200 cm yr^{-1} in Astoria (OR), 150 cm yr^{-1} in Coos Bay (OR), and 100 cm yr^{-1} in Eureka, CA. Episodic shifts in the direction of winds and other storm events can have short-term effects on coastal currents, produce aseasonal upwelling conditions, and further modify the coastal climate by the formation of dense fog, reduction of insolation, cooling the coastal air mass, and by the delivery of sudden rainstorms. Winter storms typically begin throughout the Lower Columbian Bioregion in November, and major storms can be severe with winds gusts in excess of 160 km hr^{-1} (see Figure 2.8). These winter storms also generate large ocean waves that can have significant impacts on coastal erosion, sediment transport, and deposition processes (Komar, 1998). Redistribution of sediments near river-mouths, jetties, and estuaries often contributes to hazardous bar conditions and impediments to commercial shipping.

The cool, southerly California Current system is the predominant oceanographic feature that influences coastal conditions within the Lower Columbia Bioregion. The California Current is 800 to 1,200 km wide and generally flows south at a rate of 4 to 8 km day^{-1}, although strong northwest winds can reinforce the flow and double the velocity (Figure 1.9). In the summer months a narrow, relatively fast deep-water current (California Undercurrent) flows northward at depths below 200 m (Halpern *et al.,* 1978). During late fall (late August to October) the nearshore component of the California Current weakens, although flows remain in a southerly direction farther offshore (Briggs, 1974). In winter months (November through February) the swift Davidson Current flows northward at a rate of 9 to 20 km day^{-1} at all depths across the continental margin between the California Current and the shoreline.

Upwelling of deep ocean water occurs seasonally from March to September, driven by the prevailing northwesterly winds. After several days of strong northwest winds, surface waters near the coast are driven west by the Coriolis force, away from shore. This offshore movement of surface waters causes deep, cold, nutrient-rich waters to rise to the surface (Figure 1.10). Although the most active upwelling is restricted to a narrow band approximately 8 to 24 km from shore, upwelling has a great influence over currents

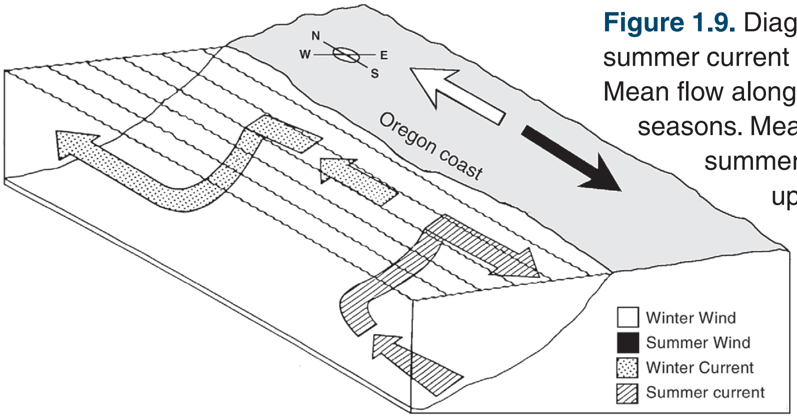


Figure 1.9. Diagram of average winter and summer current patterns off the Oregon Coast. Mean flow along the bottom is northward in all seasons. Mean surface flow southward in summer, accompanied by coastal upwelling of deeper water. Mean surface flow is northward in winter, accompanied by coastal downwelling of surface water. Adapted from Strickland and Chasan, 1989.

across the entire continental shelf. Sea surface temperatures along the open coast vary from 8 to 15 °C throughout the year (Greenland, 1998), and average sea surface temperatures range from 8.8-10.7 °C in winter to 13.4-14.8 °C in summer (Churgln and Halmiski, 1974). In contrast, subsurface temperatures (at a depth of 50 m) range from 8.3- 10.0 °C during the coldest season (usually July to September) and 10.1-10.6 °C during the warmest period (October to December; Churgln and Halmiski, 1974).

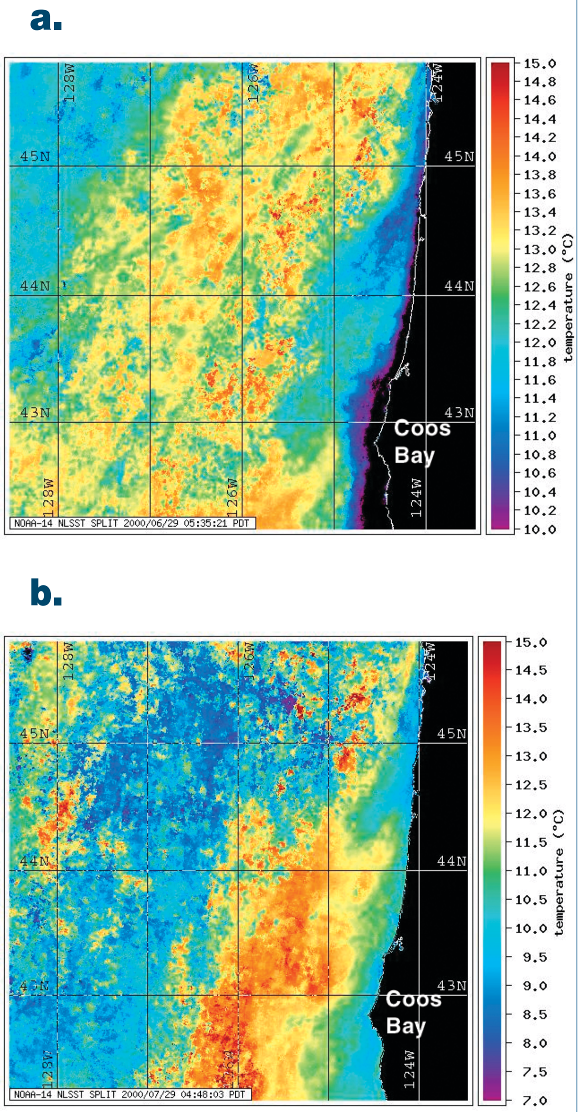


Figure 1.10. Satellite images of ocean surface temperatures off the coast of Oregon during (a) upwelling in June 2000, and (b) downwelling in July 2000. From NOAA - Coastwatch.

Upwelling of cold nutrient-rich ocean water is an important coastal process that contributes to high levels of biotic productivity throughout the Lower Columbia Bioregion. Indeed, the rates and volumes of upwelling observed in the Lower Columbia Bioregion are greater than anywhere else along the west coast of north America. Ecological importance of upwelling is demonstrated by the patchy distribution of cold-temperate faunal communities as far south as the northern coast of Baja California, where they are sustained by cool nutrient-rich waters brought up from the depths. Upwelling within the Lower Columbian Bioregion tends to be strongest between Cape Blanco (OR) and Cape Mendocino (CA).

Oregon's coastal upwelling system and associated biological production process were initially described during a period of relatively strong upwelling and high productivity (1960's and early 1970's: Peterson *et al.,* 1979; Small and Menzies, 1981; Huyer, 1983). Over the past two decades, however, average spring-summer upwelling conditions off Oregon were weak, and ocean temperatures have been above normal since the mid 1970's. This large-scale change in characteristics of the northern California Current system is widely recognized as the 1976 regime shift that marked a transition from cold to warmer ocean conditions. Responses of the marine ecosystem to decreased intensity of coastal upwelling over the past two decades are poorly understood, and the relationships between primary and secondary production, zooplankton distribution and abundance, and year-class strength for fisheries species warrant additional study.

A second regime shift may have occurred in 1998-99 that was marked by return to colder ocean conditions, increased coastal upwelling, and reestablishment of subarctic zooplankton communities within the northern California Current system (Peterson and Keister, 2001). New understandings of the ecological consequences of these oceanic regime shifts will become vitally important with regard to recent predictions of global climate change and the magnitude of ocean warming related to increases in atmospheric carbon dioxide. An improved network of coastal monitoring sites and satellite observations of the Lower Columbia Bioregion may provide an opportunity to develop a more detailed understanding of the dynamics of nearshore ocean processes including short-term variability and long-term changes in surface currents, ocean temperatures, regime shifts, and ocean productivity.

Interannual variations in the ocean environment are not well understood (Greenland, 1998) but likely play a significant role in determination of year-class strength for commercial fish stocks throughout the Lower Columbia Bioregion (Nickelson and Lichatowich, 1984; Bottom *et al.,* 1986; Bottom *et al.,* 1998). The nearshore marine environment forms a physical and biological transition zone throughout the region between dissimilar water masses (Fager and McGowan, 1963; McGowan and Williams, 1973; Favorite *et al.,* 1976). This nearshore transitional zone is strongly influenced by a mixture of cold, nutrient-rich water transported southward in the California Current and warmer water transported northward in the Davidson Current (California Undercurrent). Species composition, biomass, and production of zooplankton communities may be affected by year-to-year fluctuations in the relative strengths of ocean currents that originate in the north and south (Chelton *et al.,* 1982; Fulton and LeBrasseur, 1985). The most obvious biological effects of interannual ocean variability have occurred during unusually strong El Niño (warming) events in the eastern tropical Pacific. El Niño conditions have been associated with reports of significant range extensions for tropical plankton and other species, changes in the migration routes of salmon returning to the Fraser River (British Columbia) (Wickett, 1967; McLain and Thomas, 1983) and reduced size and fecundity of adult coho salmon off Oregon (Johnson, 1984). Relationships between these large-scale climatic processes and annual recruitment of commercial fish and shellfish species are still unclear along the coasts of northern California and Oregon.

1.1.3 Diversity of Habitats and Biotic Communities

Several different classification systems have been proposed to address global concerns over habitat loss, degradation of biotic resources, and requirements for future research (Wilson, 1988, 1992; Blockstein, 1989; McNeely *et al.,* 1990; Solbrig, 1991; Scott *et al.,* 1993; Noss, 1987, 1990). A few authors have explicitly confronted the difficulties posed by classification of biological diversity within coastal ecosystems (Ray, 1988; Grassle *et al.,* 1991; Ray and Gregg, 1991). Most notably, Ray (1991) explored application of the principles of landscape ecology to the underlying structure of coastal zone and land-margin ecosystems. As a counterpart to terrestrial systems, recognition of the spatial and temporal relationships among the primary elements of a coastal morphological unit (uplands, coastal plain, tidelands, and shoreface entrainment volume) provides a hierarchical framework for understanding biogeographical distribution of different taxonomic groups. Three avenues hold particular promise for development of meaningful seascape-level perspectives: (a) spatial considerations of coastal geomorphology and patterns of habitat diversity, (b) quantitative descriptions of species assemblages as indicators of ecotone boundaries, and (c) incorporation of experimental and anecdotal information regarding species responses, feedbacks, and life-histories (Ray, 1991).

The Lower Columbia Bioregion encompasses a wide diversity of habitats, and relationships among various components of the coastal ecosystems are complex and dynamic. Geomorphic differences in the coastal mountain range and shoreline contribute to formation of sandy beaches, rocky shores, reefs, and islands along the coasts of Oregon and northern California. Numerous drowned river mouth estuaries occur south of the Columbia River, and two large estuaries occur immediately to the north (Willapa Bay and Grays Harbor, WA). These coastal habitats form the basis for highly productive marine and coastal ecosystems that support many species of seabirds, marine mammals, and a wide variety of commercially and recreationally important fish and shellfish. Most populations of marine fish and shellfish are relatively healthy despite significant declines in Pacific salmon and indications of probable declines in some populations of exploited rockfish and groundfish.

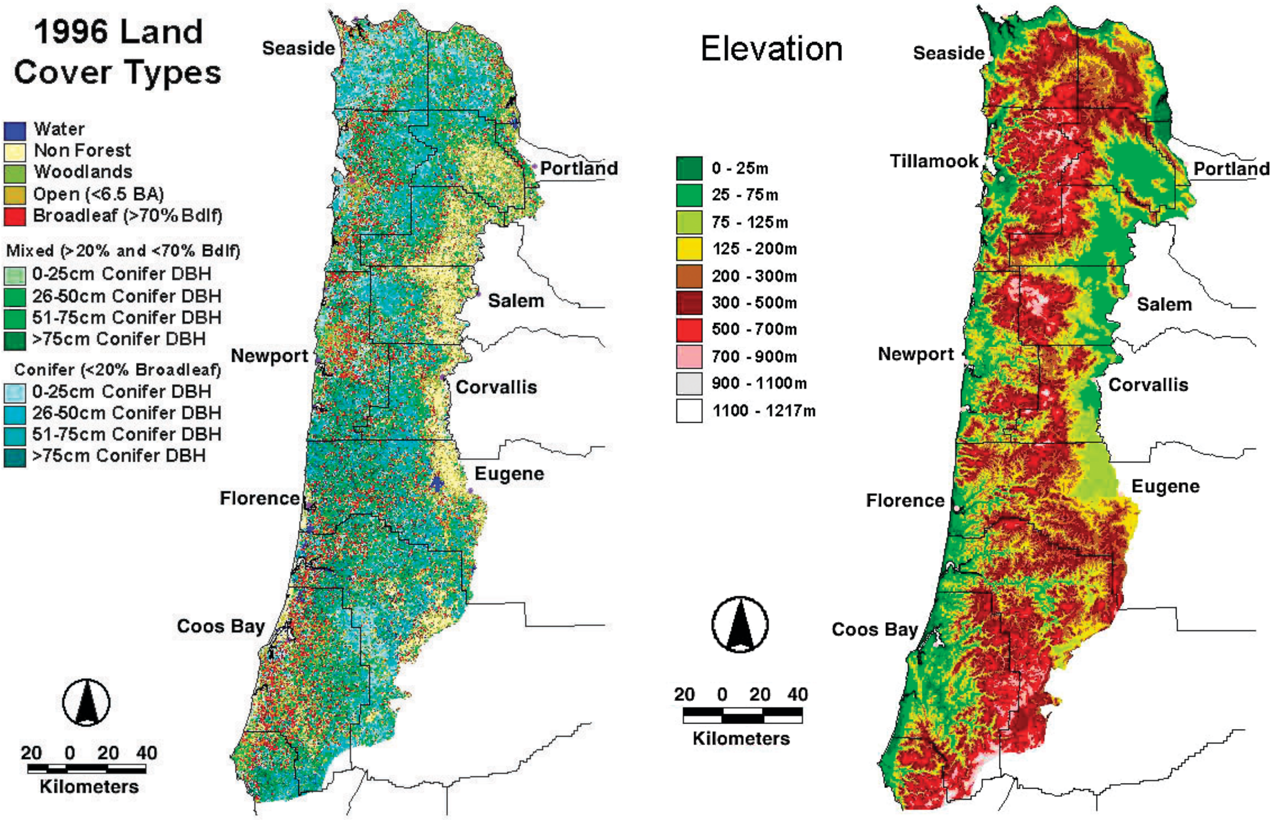


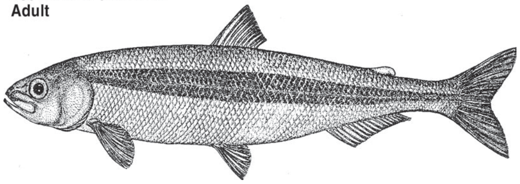
Figure 1.11. Land cover types (1996) and elevation within the Oregon Coast Range (adapted from Oregon State University/CLAMS: Coastal Landscape Analysis and Modeling Study).

Coastal vegetation within the Lower Columbia Bioregion is dominated by several species of conifers and broad-leafed deciduous trees (Figure 1.11). The region is classified as part of the Humid-Temperate Domain (Bailey, 1989) and as the Coast Range Province (Omernik, 1987; Omernik and Gallant, 1986) with marine western coniferous and mixed-forests along the coast from Astoria (OR) to Coos Bay (OR), and oceanic forest / tundra south to Mendocino (CA). The dominant forest types are: (a) Douglas-fir, Sitka spruce, western red cedar, western hemlock along the Oregon coast, and (b) western red cedar, western hemlock, Douglas-fir, and coastal redwood forests along the foggy coastline of northern California. Heavy logging and a series of extensive wildfires during the last century eliminated most late-successional old-growth forests from the northern section of the bioregion, and older forests in the southern section are highly fragmented. Even before the advent of fire suppression, forests within the coastal zone were subject to infrequent lightning fires (Agee, 1993). As a result of the long fire-return interval (over 1,000 yrs) and protection of forested riparian areas from burns and blowdown, many of the remaining natural forests consist of a mosaic of mature stands and remnant patches of old-growth trees (FEMAT, 1993).

Many assemblages of temperate marine and estuarine organisms found within the Lower Columbia Bioregion are composed of species with centers of distribution further to the north or south. For example, recent assessments of macrobenthic algae and seagrasses along the Oregon coast indicate that the seaweeds and kelps have high affinities with communities from SE Alaska - Washington, although many of the Oregon taxa may have been overlooked because of their small size, crustose morphology, or subtidal habitat (Goddard, 1997). Several anadromous species of fish that occur within the Lower Columbia Bioregion (*i.e.,* cutthroat, steelhead, coho, chinook, chum, and pink salmon) also have centers of distribution to the north, while other fishes (*i.e.,* Pacific sardine, bay pipefish, staghorn sculpin, shiner perch, topsmelt) have geographic centers of distribution further south (Figure 1.12; Monaco *et al.,* 1992). In contrast, other characteristic assemblages of marine and estuarine organisms occur throughout the Lower Columbia Bioregion that are distinct from the more boreal communities to the north. Several species of sculpins (Cottidae; including the cabezon, brown Irish lord, and darter, longfin, rosylip, saddleback, thornback and threadfin sculpins) have centers of geographic distribution in the Lower Columbian Bioregion, but the range of these species extends north and south into adjacent transitional areas (Miller and Lea, 1972; Monaco *et al.,* 1992). Characteristic shellfish and invertebrates that occur within the bioregion include Dungeness crabs, razor clams, ocean pink shrimp, and the introduced Pacific oyster (*Crassostrea gigas*).

Diverse assemblages of marine mammals occur in nearshore areas throughout the Lower Columbia Bioregion. Harbor seals (*Phoca vitulina*) are year-round coastal residents that commonly inhabit nearshore rocks, islands, and protected bays. Large numbers of California sea lions (*Zalophus californianus*) and Stellar

Hypomesus pretiosus
Adult



Estuary	A	S	J	L	E
Puget Sound	◉	●	◉	◉	●
Hood Canal	◉	●	◉	●	●
Skagit Bay	◉	●	◉	●	●
Grays Harbor	○		○	○	
Willapa Bay	○		○	○	
Columbia River	○		◉	○	
Nehalem Bay	●		●	○	
Tillamook Bay	●		●	○	
Netarts Bay	√		●	○	
Siletz River	◉		◉	○	
Yaquina Bay	○		●	○	
Alsea River	○		●	○	
Siuslaw River	●		●	○	
Umpqua River	●		●	○	
Coos Bay	◉		●	○	
Rogue River	√		◉	○	
Klamath River	√		○		
Humboldt Bay	○		◉	○	
Eel River	○		●	○	
Tomales Bay	○		○	○	
Cent. San Fran. Bay*	√		√		
So. San Fran. Bay	√		√		
Elkhorn Slough			√		
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

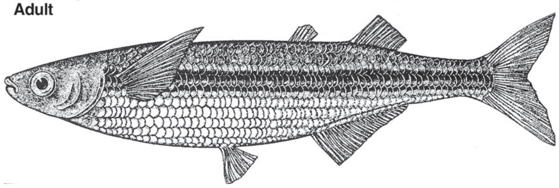
Life Stage

Relative abundance:
● Highly abundant
◉ Abundant
○ Common
√ Rare
Blank Not present

Life Stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Atherinops affinis
Adult



Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor	√		√		
Willapa Bay	√		√		
Columbia River	√		√		
Nehalem Bay	√		√		
Tillamook Bay	○		○		
Netarts Bay	◉	◉	◉	○	◉
Siletz River					
Yaquina Bay	◉	◉	●	○	◉
Alsea River	○	○	○	○	○
Siuslaw River	◉	◉	◉	○	◉
Umpqua River	○		○		
Coos Bay	●	●	●	○	●
Rogue River					
Klamath River					
Humboldt Bay	○	○	○	○	○
Eel River	○	○	○	○	○
Tomales Bay	◉	◉	●	◉	◉
Cent. San Fran. Bay*	○		○	○	
So. San Fran. Bay	◉	●	●	◉	●
Elkhorn Slough	●	●	●	◉	●
Morro Bay	●	●	●	◉	●
Santa Monica Bay	◉	○	◉	○	○
San Pedro Bay	◉	○	◉	○	○
Alamitos Bay	◉	◉	●	◉	◉
Anaheim Bay	◉	◉	●	◉	◉
Newport Bay	◉	◉	●	○	◉
Mission Bay	◉	◉	●	○	◉
San Diego Bay	◉	◉	●	○	◉
Tijuana Estuary	●	●	●	●	●
	A	S	J	L	E

Life Stage

Relative abundance:
● Highly abundant
◉ Abundant
○ Common
√ Rare
Blank Not present

Life Stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Figure 1.12. Biogeographic differences in the distribution of Surf smelt and Topsmelt throughout Pacific coast estuaries from Puget Sound, WA to Tijuana Estuary, CA. Surf smelt are found more commonly in northern estuaries, while Topsmelt have a more southerly distribution. Adapted from Emmett *et al.,* 1991.

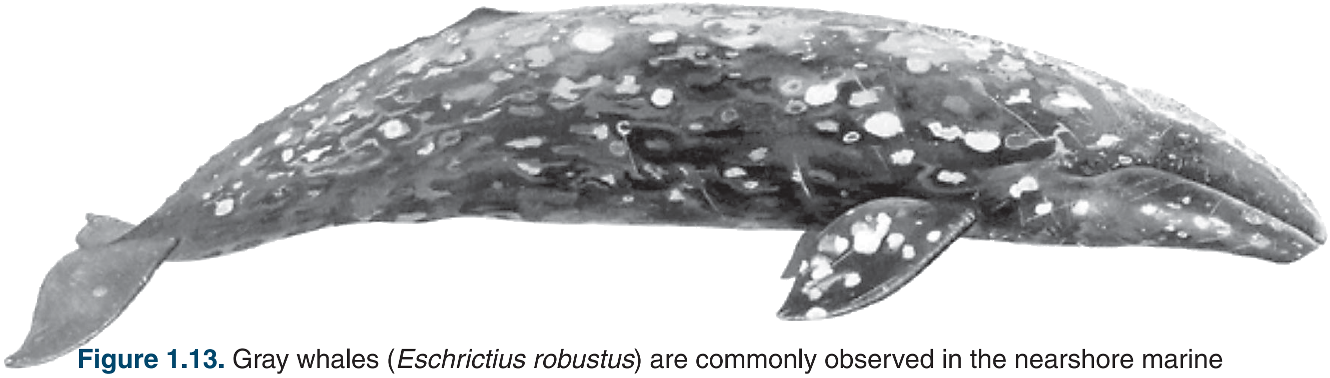


Figure 1.13. Gray whales (*Eschrictius robustus*) are commonly observed in the nearshore marine waters during annual migrations. Gray whales occasionally enter the Coos estuary where they have explored the marine-dominated region to river mile 9.

sea lions (*Eumetopias jubatus*) occur in a variety of nearshore habitats in the fall, winter and early spring (NOAA, 1988), while smaller numbers of northern elephant seals (*Mirounga angustirostris*) and northern fur seals (*Callorhinus ursinus*) are found in isolated locations or in offshore waters. Gray whales (*Eschrichtius robustus*) are commonly seen as they migrate close to shore between their summer feeding grounds in the Arctic and their winter calving lagoons in Baja California, and immature individuals may remain along the coasts of Oregon and northern California during the summer months (Figure 1.13). Small cetaceans including harbor porpoise (*Phocoena phocoena*) and Pacific white-sided dolphin (*Lagenorhyncus obliquidens*) occur in nearshore waters, and common dolphin (*Delphinus delphis*) and Dall's porpoise (*Phocenoides dalli*) are often seen in continental shelf waters. Several other cetaceans including minke whales (*Balaenoptera acutorostrata*), fin whales (*B. physalus*), sei whales (*B. borealis*), humpback whales (*Megaptera novaeangliae*), and orca (*Orcinus orca*) are occasionally seen in offshore waters over the continental shelf. Further offshore blue whales (*B. musculus*), right whales (*Eubalaena glacialis*), and sperm whales (*Physeter macrocephalus*) are sometimes seen at sea.

The coastal avifauna is extensive within the Lower Columbia Bioregion (Graybill and Hodder, 1985). Diverse communities of resident and migratory shorebirds and waterfowl utilize a variety of different coastal habitats for resting areas, breeding, and forage. Although fewer nesting birds occur here than in the Upper Columbian Bioregion immediately to the north, about 1.5 million seabirds breed annually along the coasts of Oregon and northern California (NOAA - USFWS, 1991). Over 50% of the nesting seabirds found on the entire contiguous U.S. Pacific shoreline (WA, OR, CA) occur along the Oregon coast. Large breeding colonies of common murre (700,000 birds) and Leach's storm petrel (460,000 birds) are particularly important, while significant breeding colonies (more than 10 percent of the northeast Pacific total) also occur for western gull, double-crested cormorant, Brandt cormorant, Caspian tern, and black oystercatcher (Figure 1.14). The Lower Columbia Bioregion is the

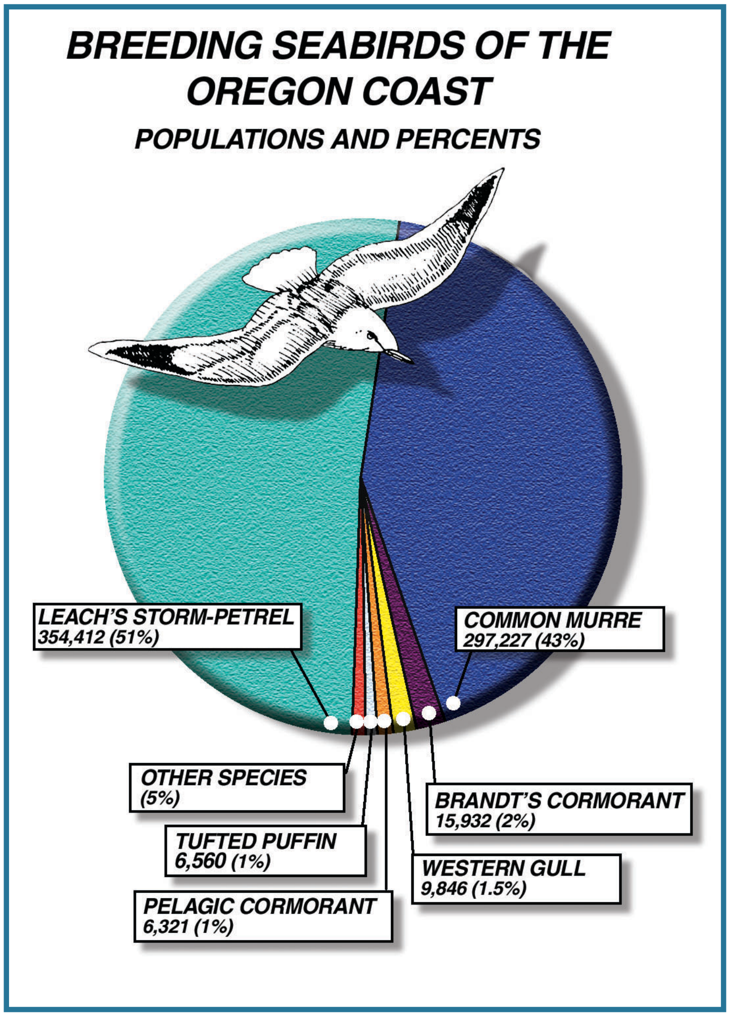


Figure 1.14. Breeding seabirds of the Oregon coast. Diagram illustrates the proportion of the total seabird population contributed by the six most abundant species. From the Oregon Ocean Book, 1985.

winter home for numerous other species that range over the open ocean such as the northern fulmar, sooty shearwater, and black-footed albatross. Migratory shorebirds and waterfowl include the common loon, grebes (red-necked, horned, and western), brant, surf scoters, red phalarope, and sanderling. Year-round residents include the pigeon guillemont, auklet, tufted puffin, and pelagic cormorant.

1.2 Estuaries in the Lower Columbia Bioregion

Estuaries are well represented throughout the Lower Columbia Bioregion where they encompass the broad range of land-margin habitats between freshwater and marine ecosystems. These land-margin ecotones are highly dynamic systems that provide support for a variety of living resources, critical physical processes, and essential ecological functions. Estuarine habitats are of special importance to populations of resident and migratory shorebirds, waterfowl and raptors, and they sustain productive sites for commercial and recreational shellfish harvests, aquaculture operations, and communities of estuarine and anadromous fish. Critical physical processes and essential ecological functions carried out within estuaries include stormwater management and flood control, trapping of sediments and non-point source pollutants by salt marshes and eelgrass beds, and the provision of nesting and forage areas for birds, fish, and marine mammals. Estuaries and coastal wetland habitats also provide nursery sites and transitional zones for juvenile crabs, bottom fish, and young salmon (chinook, coho, chum), and they serve as a source of suspended nutrients, organic materials, and detritus for filter-feeding and deposit-feeding invertebrates (burrowing clams, shrimp, amphipods, and polychaete worms). Harsh physical conditions that typify most estuaries exert a profound impact on the species composition and distribution of plants and animals that inhabit tidal channels, mud and sandflats, and salt marshes.

1.2.1 Definition and Classification of Estuaries

Estuaries and coastal ecosystems located within the Lower Columbia Bioregion can be broadly defined as land-margin ecosystems that occur at the interface between steep or deltaic riverine valleys and the nearshore marine waters of the Pacific Ocean. Functional definitions for estuaries range from the fundamental delineation: (a) an arm or inlet of the sea where freshwater mixes with saltwater (Thom, 1987); to more specific geomorphic descriptions: (b) a semi-enclosed coastal water body with a free connection with the open sea and within which sea water is measurably diluted with freshwater (Pritchard, 1967); or (c) an inlet of the sea that reaches into a river valley as far as the upper limit of tidal rise; to (d) holistic consideration of the entire land-margin ecosystem as that portion of the earth's coastal zone where there is interaction of ocean water, fresh water, land, and the atmosphere (Day *et al.,* 1989). Pacific northwest

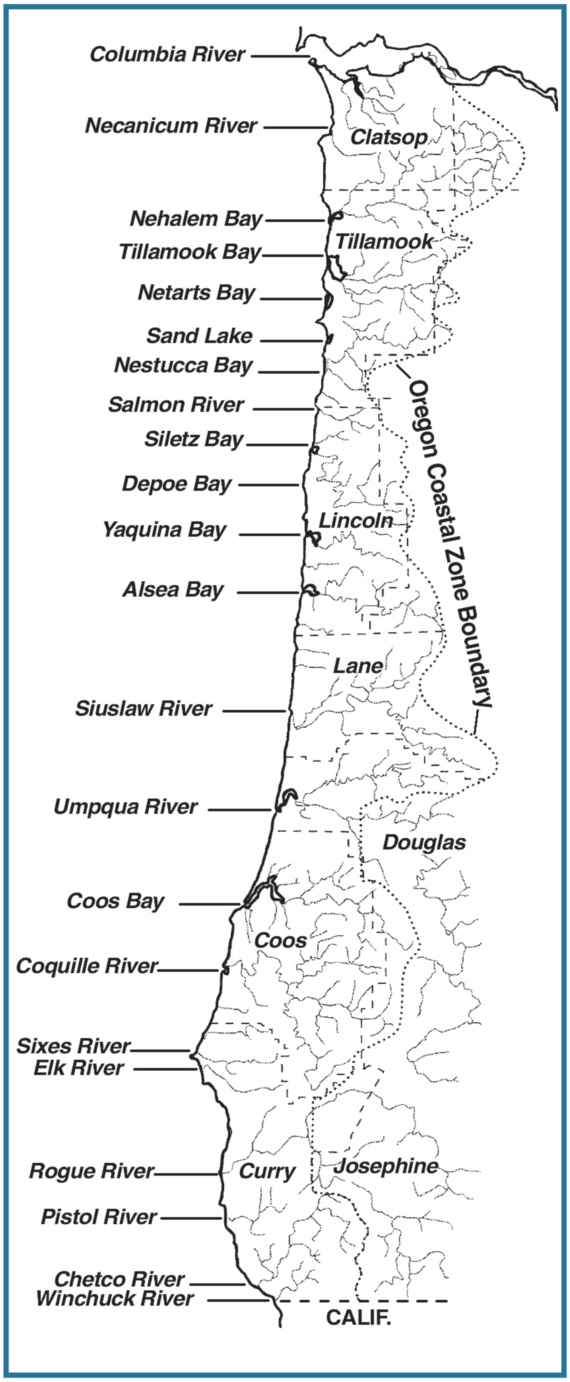


Figure 1.15. Map of Oregon estuaries. From the Oregon Estuary Plan Book, 1987.

estuaries are generally divisible into a *marine or lower estuary* in free or moderately restricted connection with the nearshore ocean, a *middle estuary* subject to strong mixing of salt and freshwater, and an *upper or fluvial estuary* characterized by freshwater but subject to daily tidal action (Fairbridge, 1980).

Estuaries throughout the Lower Columbia Bioregion occur in a variety of landforms situated within relatively steep and forested watershed basins (Figure 1.15). Geomorphic typologies of the estuaries include: (a) river-dominated drowned river-mouths, (b) tidal-dominated drowned river-mouths, and (c) embayments and coastal lagoons (Duxbury, 1987). The drowned river-mouth estuaries are the most prevalent and include numerous tidal-dominated systems (*i.e.,* Tillamook Bay, Siletz Bay, Yaquina Bay, Alsea Bay, Coos Bay, Humboldt Bay) and several river-dominated systems (*i.e.,* Columbia River, Umpqua River, Rogue River, Klamath River). Many of the tidally-dominated drowned river-mouth systems are protected from ocean surf and winds by elongated sand spits and narrow coastal dunes. In contrast, the embayments and lagoonal estuaries are primarily smaller bar-built systems (*i.e.,* Netarts Bay, Sand Lake, Stone lagoon, Big Lagoon) and blind river-mouths (*i.e.,* New River, Elk River, Sixes River, Pistol River). Geomorphic limits of the estuarine systems extend upstream and landward to the location where ocean-derived salts measure less than 0.5 psu (practical salinity units) during the period of average annual low riverine flow (Cowardin *et al.,* 1979). The seaward limit of the estuarine system is typically defined as: (a) a line closing the mouth of a river, bay, or sound; (b) a line enclosing an offshore area of diluted seawater with typical estuarine flora and fauna; or (c) the seaward limit of wetland emergent vegetation, shrubs or trees where these plants grow seaward of the line enclosing the mouth of a river, bay or sound.

Although hydrological circulation patterns within the regional estuarine basins are complex and poorly understood, the estuaries can be broadly divided into bay and slough subsystems, and into a series of four distinct geomorphic zones (Figure 1.16). The marine–

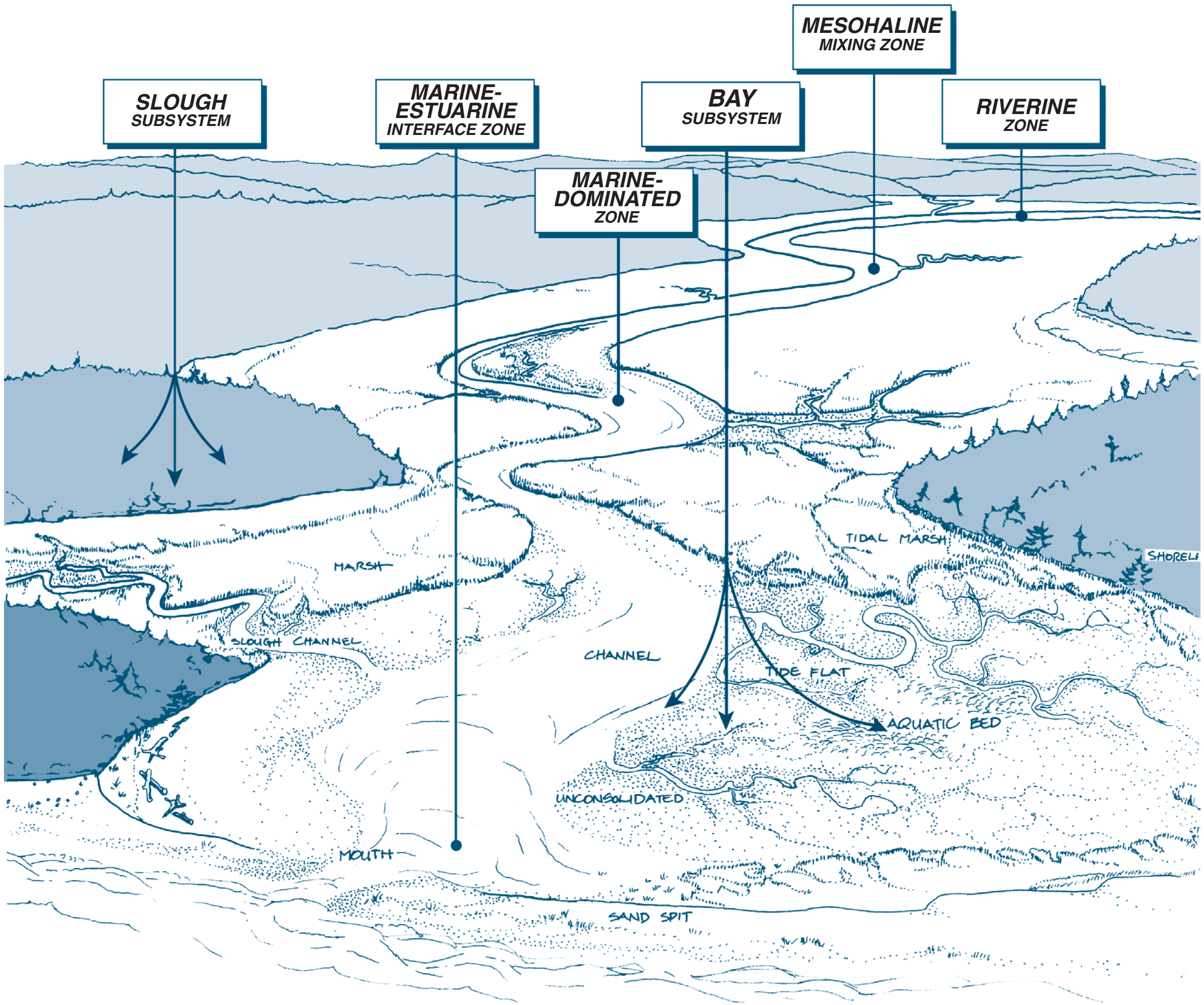


Figure 1.16. Major subsystems and zones of Pacific Northwest estuaries. Adapted from The Oregon Estuary Plan Book, 1987.

estuarine interface zone is located immediately outside the mouth of the estuary and characterized by marine waters with a salinity range of 33 to 25 psu. In some cases the marine-estuarine interface zone can be expansive (*i.e.,* Columbia River plume) and extend over thousands of hectares and hundreds of kilometers from the point of discharge into sea. In other cases the marine-estuarine interface zone is relatively small and confined to the region of mixing between marine and estuarine waters with the daily ebb and flood of the tides. The marine-dominated lower zone is located immediately inside the mouth of the estuary and is characterized by polyhaline waters with a salinity range of 30 to 18 psu. Further up the estuary, the middle estuary mixing zone is located at variable distances from the mouth and is characterized by mesohaline waters with a salinity range of 18 to 5 psu. The upper estuary riverine zone is located near the head of tide and is characterized by input of oligohaline waters with a salinity range of 5 to 0.5 psu. Tidal exchange in the Pacific northwest estuaries may be partial or nearly complete, and the tides are mixed and semi-diurnal with a typical range of 2.4 to 3.3 meters.

Detailed habitat classification systems have been developed specifically for Pacific northwest estuaries by Bottom *et al.,* (1979), Dethier (1990), and Simenstad *et al.,* (1991). These estuarine classification systems are regional derivatives of the U.S. Fish & Wildlife Service Wetland Classification Scheme (Cowardin *et al.,* 1979) and they incorporate the hierarchical breakdown of estuarine subsystems based on tidal regime, substratum class, representative fish and wildlife assemblages, and other modifiers (Figure 1.17). Designation of levels of physical energy imparted by exposure to waves and currents adds another important tier to the hierarchy (Dethier, 1990) because the soft sedimentary substrata within estuarine tidelands and channels are prone to resuspension and redistribution by tidal currents and fetch waves. Although estuaries of the Lower Columbia Bioregion exhibit striking geomorphic differences compared with their counterparts on the Atlantic and Gulf coasts (Hayden *et al.,* 1984), similarities in the fundamental landscape units for these coastal land-margin ecosystems are indicative of the broad application of the Cowardin classification system.

1.2.2 Regional Estuarine Management Concerns

Tidal channels, tideflats, marshes, embayments, and sandy barrier spits that characterize the outer coast estuaries of Oregon and northern California are dynamic coastal ecotones that respond readily to

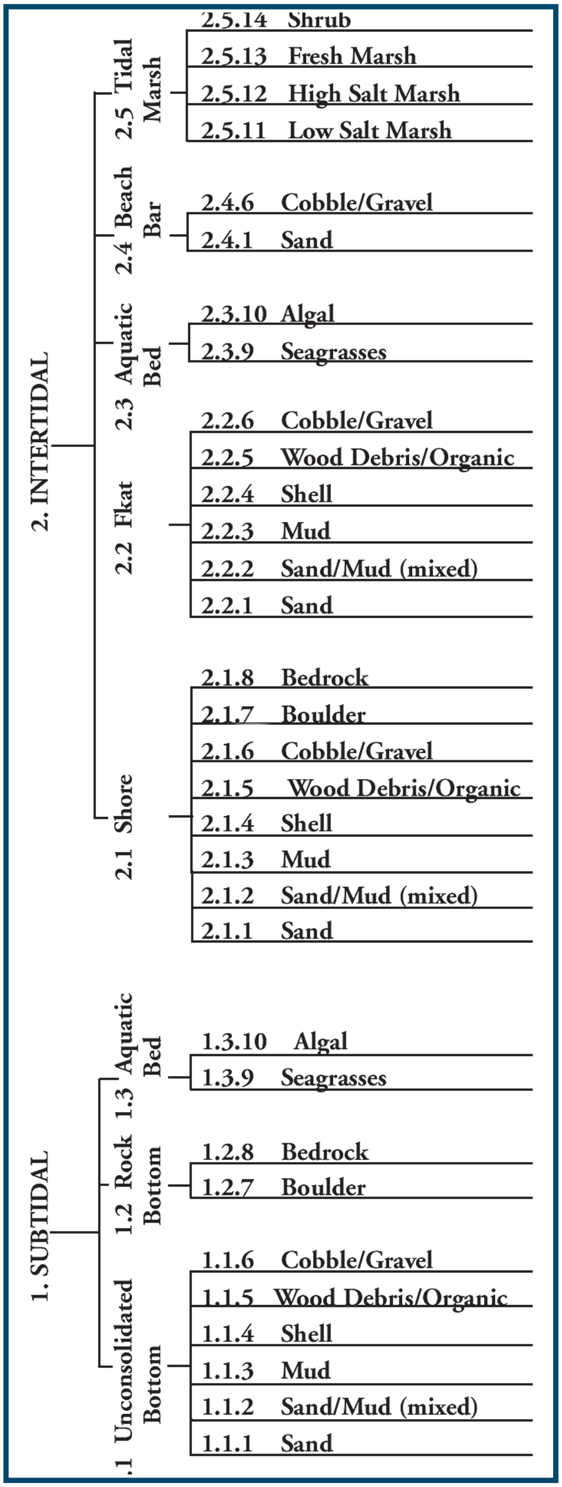


Figure 1.17. Oregon Estuarine Habitat Classification System. From the Oregon Estuary Plan Book, 1987.

disturbance by natural and anthropogenic events. The long-term health and sustained productivity of these Pacific northwest estuarine ecosystems are priority areas for national concern, and particular attention should be focused on the chronic adverse effects of anthropogenic disturbances and ecological

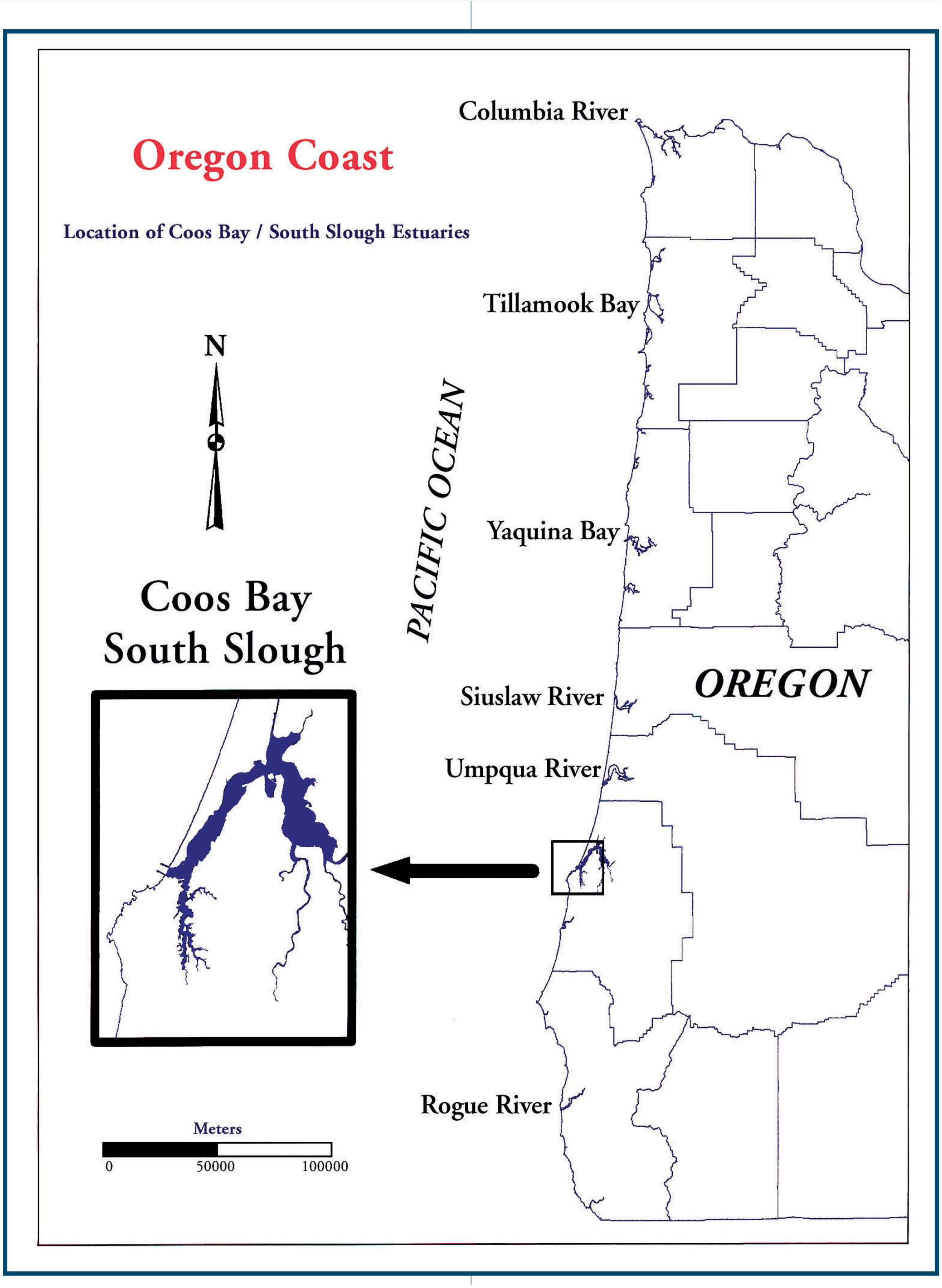


Figure 1.18. Location of the Coos estuary and South Slough on the southern Oregon coast.

stressors (*i.e.*, invasive species, industrial contaminants, aquaculture operations, habitat alterations, shoreline development, and recreational activities) on the physical structure and ecological functions of estuarine habitats. State and federal resource agencies are encouraged to develop cost-effective and reliable methods to assess existing and future habitat values in an effort to guide land-use planning and informed coastal decisionmaking. It has become clear that effective management of the Pacific northwest estuarine ecosystems requires a comprehensive understanding of: (a) fundamental ecological components and processes within targeted estuarine habitats, (b) empirical studies that provide detailed knowledge of the community and habitat responses to natural and anthropogenic stresses, and (c) reliable predictive models and an integrated and adaptive management framework that can rapidly incorporate scientific results into new policies and practices.

1.3 Coos Watershed and Estuary

The Coos watershed is a steeply forested coastal drainage basin located within the south-central region of the Oregon coast range (Figure 1.18). The watershed basin has a planar surface area of about 157,645 ha (608 sq miles), and the terrain is deltaic in the bottomlands with moderately rugged hills and ridgetops that reach elevations of 600 m (Figure 1.19).

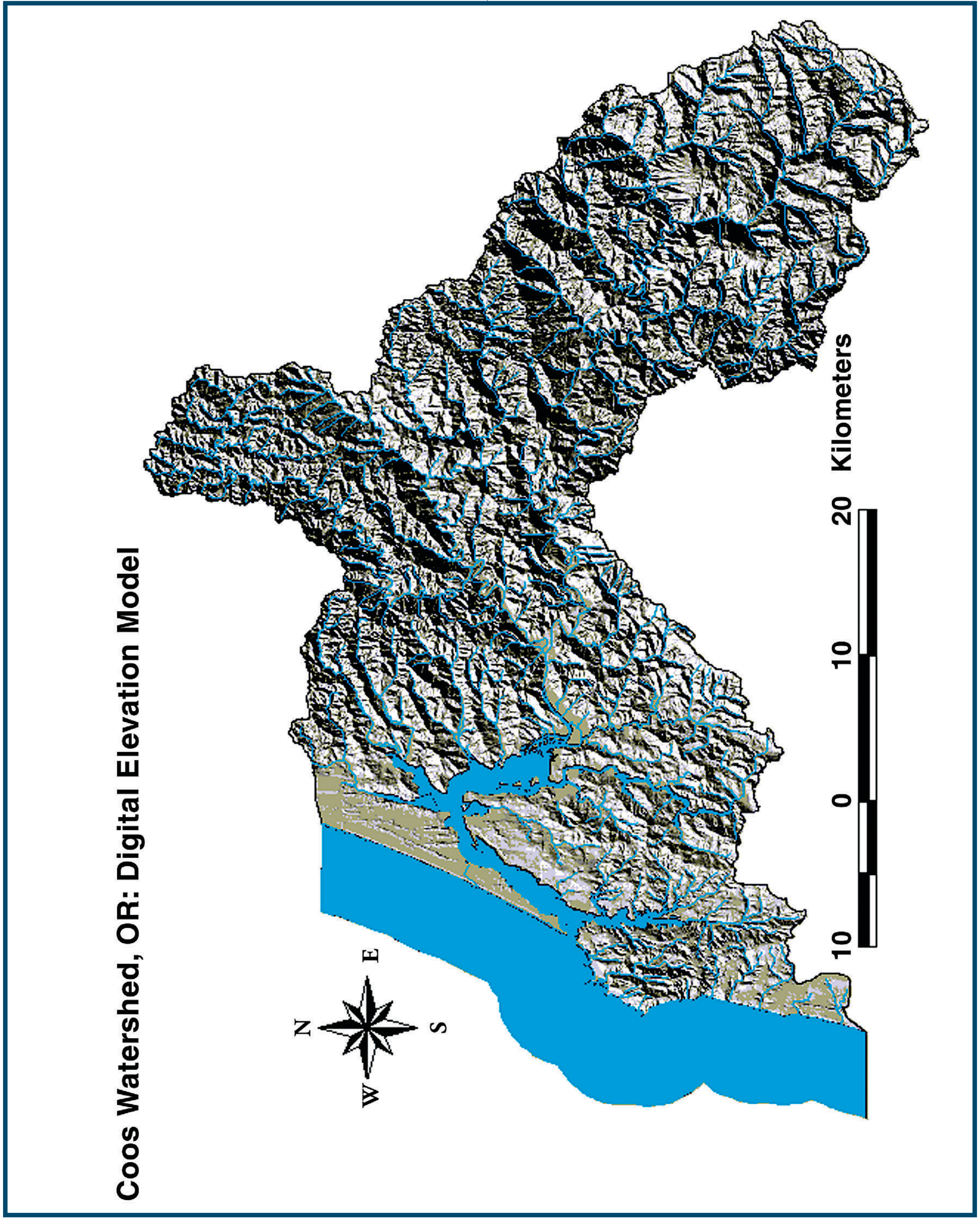


Figure 1.19. Shaded relief Digital Elevation Model (DEM) of the Coos watershed, OR.

The Coos watershed drainage basin is composed of a relatively thick sequence of uplifted and tilted sedimentary rocks in an area of apparent crustal weakness. Eocene bedrock layers and older basin materials have been subjected to greater deformation than similar strata elsewhere in Coos County. Stratigraphic bedding dips have been measured at angles up to 70% which are much steeper than adjacent areas (ACOE, 1993). Rainfall along the shoreline of the estuary (North Bend) averages 148 cm yr^{-1}, although precipitation can reach over 250 cm yr^{-1} within the mountains of the Elliott State Forest. Two primary rivers: (a) the south fork of the Coos River, and (b) the west fork of the Millicoma River flow through the majority of forest lands within the drainage basin. These rivers converge in the lower watershed to form the Coos River, which meanders westward for 6.5 km before entering the Coos estuary. Approximately 88% of the Coos watershed is managed for the commercial production of timber, and the steep forested hillsides are covered by a mosaic of maturing stands and recovering clearcuts that are in private and public ownership.

1.3.1. Physical Description of the Coos Estuary

The Coos estuary encompasses about 5,383 ha (54 km^2) and is the sixth largest estuary along the Pacific coast of the contiguous United States (Proctor *et al.,* 1980; NOAA, 1992). As the largest estuary located completely within Oregon state lines, the Coos estuary is Oregon's most important coastal industrial center and shipping port with direct commercial ties to San Francisco, the Columbia River, Puget Sound, and other major port facilities throughout the Pacific rim (Figure 1.20). The Coos estuary is classified as a Deep Draft Development Estuary (Cortright *et al.,* 1987) and its entrance is stabilized and protected by a pair of 1 km rock jetties. The navigational channel within the Coos estuary is routinely dredged to maintain adequate depths for commercial shipping, and the shoreline contains special zoning units for: (a) urban and industrial development, (b) conservation of natural resources, and (c) natural management of significant fish and wildlife habitats. Like many other Pacific northwest estuarine systems, the Coos estuary is a drowned river-mouth that was inundated by tidal waters during the most recent transgression of sea level (beginning *ca.* 20,000 years ago; Thompson *et al.,* 1993).

Entrance to the Coos estuary is located on the southern Oregon coast (43.35°N, 124.34°W) about 322 km south of the Columbia River and 716 km north of San Francisco Bay. Tidal waters of the Coos estuary are protected from the Pacific Ocean by an elongated 11 km sandy barrier (North Spit), and the mouth of the estuary is marked by a rocky headland (Coos Head) that is exposed to the full force of ocean waves. The shallow tidal basin is formed by the confluence of Isthmus, Catching, and Coalbank Sloughs (south-east), Kentuck and Willanch Inlets (east), North Slough and Hayes Inlet (north-east), Pony Slough (north-west), and South Slough and Joe Ney Slough (south-west). Each of these slough systems occur at the mouths of distinctive watershed sub-basins, and they provide conveyance systems for drainage of several short (16-19 km) perennial streams. The shoreline of the Coos estuary is bordered by the municipalities and cities of Charleston, Barview, Empire, North Bend, Coos Bay, Millington, Eastside, and Glasgow with a collective population of about 36,000 people in 2000. Deep draft navigation and commercial shipping activities are limited to the lower 24 km of the estuary, and tidal waters of the estuary are fed by the Coos River and several perennial and intermittent streams that drain the western slopes of the Oregon coast range. Extensive tidelands (primarily sand flats, mudflats, and salt marshes) comprise about 60-70% of the planar surface of the estuary, and depth of the navigational channel varies from 10-14 m below Mean Lower Low Water (MLLW). Upstream from the city of Coos Bay the average channel depth decreases to about 9 m below MLLW.

1.3.1.a Tidal Hydrology of the Coos Estuary

The Coos estuary is a drowned river-mouth basin with an average water surface area of 5,010 ha and an estimated tidal prism volume of about 765 million m^3 (1.89 X 10^9 ft^3; Johnson, 1972). The relatively shallow estuary has a mean depth of 2 m below MLLW, and broad expanses of tideflats and mud are exposed at low tide. Tidal currents are substantial throughout the estuary with average flows over 1 ms^{-1} and maximum recorded rates of 1.7 ms^{-1} (Baptista, 1989). Shallow depth of the Coos estuary allows thorough mixing of fresh and saltwater for most of the year. Seasonally high volumes of freshwater, however, cause the estuary to become partially stratified in winter, particularly in areas where the deep navigational channel has been dredged for

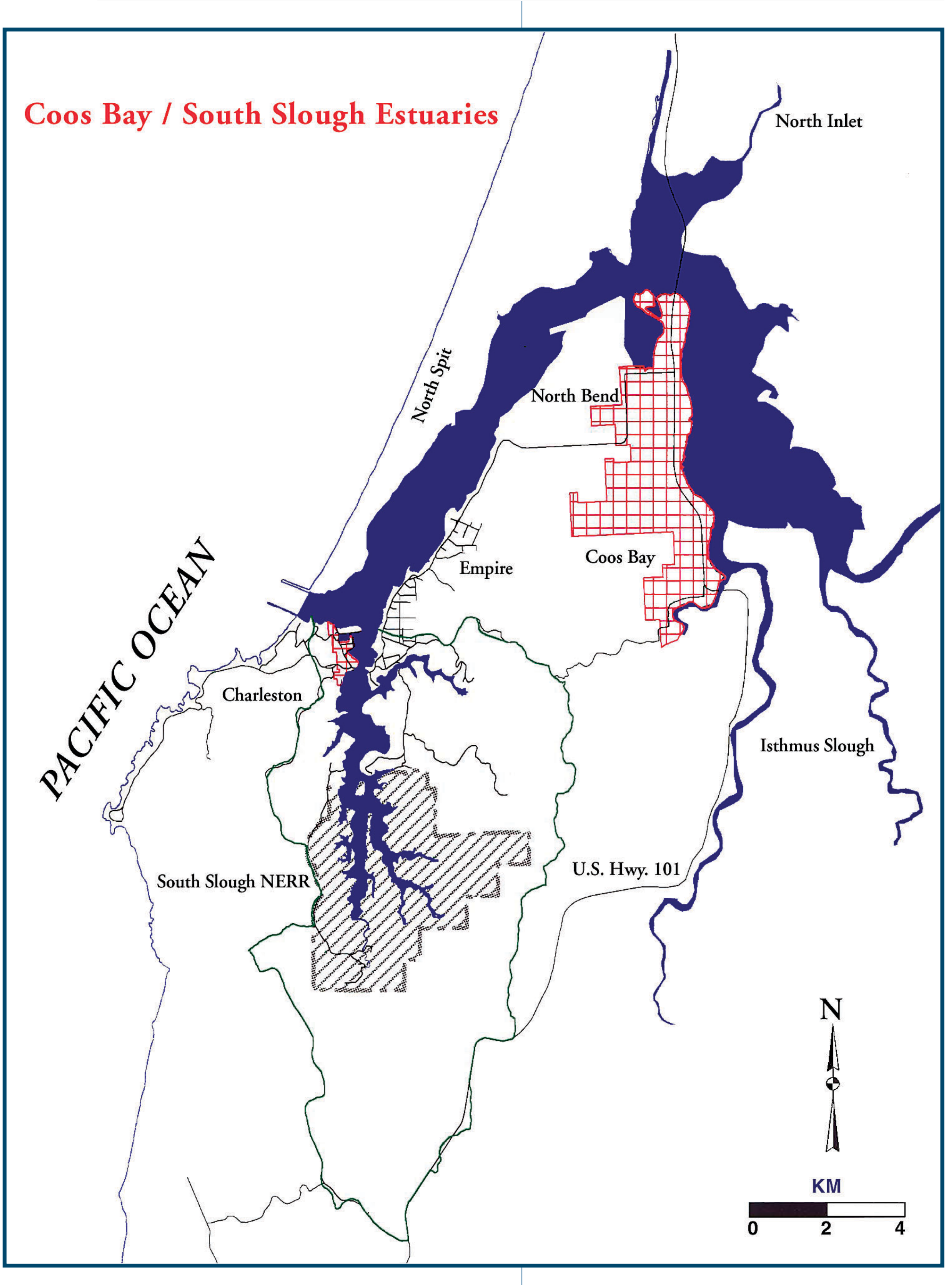


Figure 1.20. Coos Bay/South Slough estuary and location of South Slough National Estuarine Research Reserve (NERR).

shipping. In some cases tidal overmixing (high surface salinity and lower bottom salinity) has been noted (McAllister and Blanton, 1963; Arneson, 1976) due to the confined mixing of distinct water masses by strong tidal currents. Freshwater flow into the Coos estuary during winter rains (January to April) averages 5,500 cfs while inflows drop to 90 cfs from May through December (ACOE, 1993). The Coos estuary receives an average annual runoff of about 2.3 million acre-feet, and about 66% of the freshwater enters through the Coos and Millicoma Rivers.

Rates of sediment deposition within the Coos estuary are greater than the rates of transport and removal through the tidal channels. Consequently, the estuary is an aggrading system that is slowly filling with sand, silt, and organic materials carried by the rivers and tidal currents at an average annual rate of about 1.6 million y^3 per year. Storm-driven waves and tidal scour result in periodic redistribution of sediments, and large quantities of submerged materials are redeposited in association with seasonal freshets and episodically high freshwater inputs (ACOE, 1975).

Water quality in the upper regions of the Coos estuary is frequently degraded, and the mid portions of the tidal basin are conditionally approved for shellfish harvests. The moderately polluted conditions are typical of an urbanized shoreline and industrial shipping port. Water quality problems in the shallow estuary are compounded by low flushing rates (10-20 days in winter and spring; 20-40 days in summer (Arneson, 1976) and relatively low levels of freshwater input (Bricker *et al.,* 1999). Warm surface water temperatures, high fecal coliform bacteria counts, and elevated turbidity levels occur intermittently at various locations throughout the estuary, particularly during July – September (Roye, 1979). Transport and decay of organic materials carried into the estuary contribute to a high biological oxygen demand (BOD) and low levels of dissolved oxygen (hypoxia). Problems with high turbidity and hypoxia (O_2<3 mg/L) are most prevalent in Isthmus Slough at a location about 20 km above the mouth. Tides in the Coos estuary are mixed and semidiurnal with a mean tidal range of 2.3 m at the mouth and 2.2 m at the City of Coos Bay (Figure 1.21). The highest tides are 3.3 m above MLLW and extreme low water levels occur at –0.9 m below MLLW (extreme tidal range is 3.4 m). Tidal influence extends nearly 50 km up the Coos River to the town of Allegeny.

1.3.1.b Local Climate

Local climate conditions in the immediate vicinity of the Coos estuary are typical for the southern Oregon coast with cool dry summers and mild, cloudy, wet winters. Approximately 142 cm of rain falls on the estuary from October through May, with an average monthly rainfall of 40 cm in January (the wettest month). Monthly rainfall drops to less than 10 cm from June through September with less than 2 cm in July (the driest month; see Figure 1.8). Long-term precipitation rates averaged 152.4 cm yr^{-1} over a period of 80 years at the North Bend Observation Station (Baptista, 1989). Extreme air temperatures can

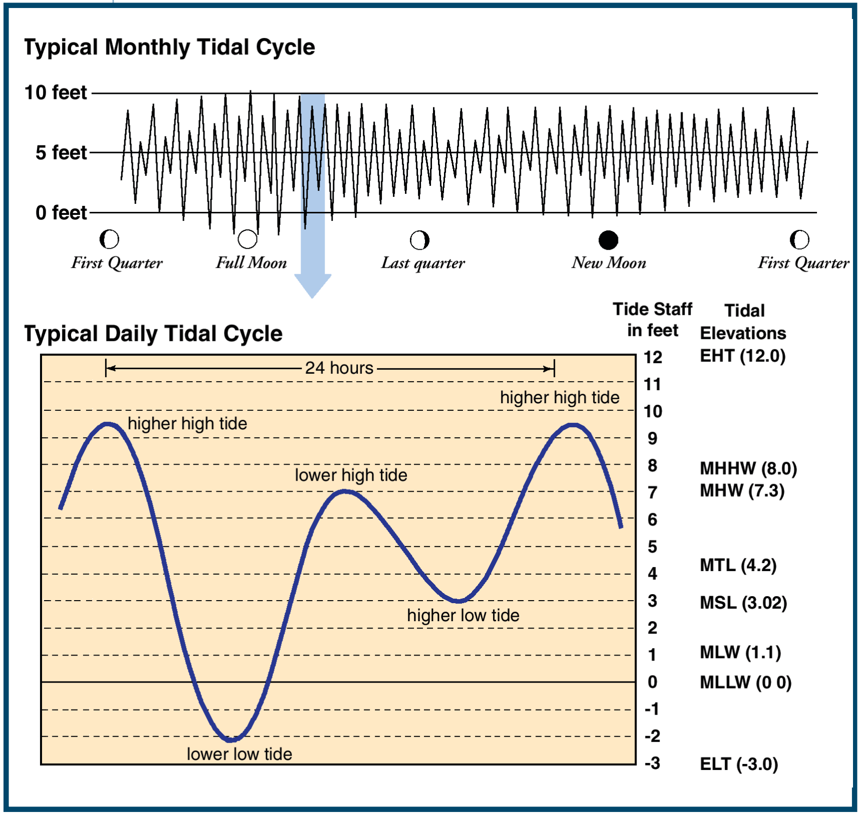


Figure 1.21. Mixed semi-diurnal tides along the Oregon coast and within the Coos estuary.

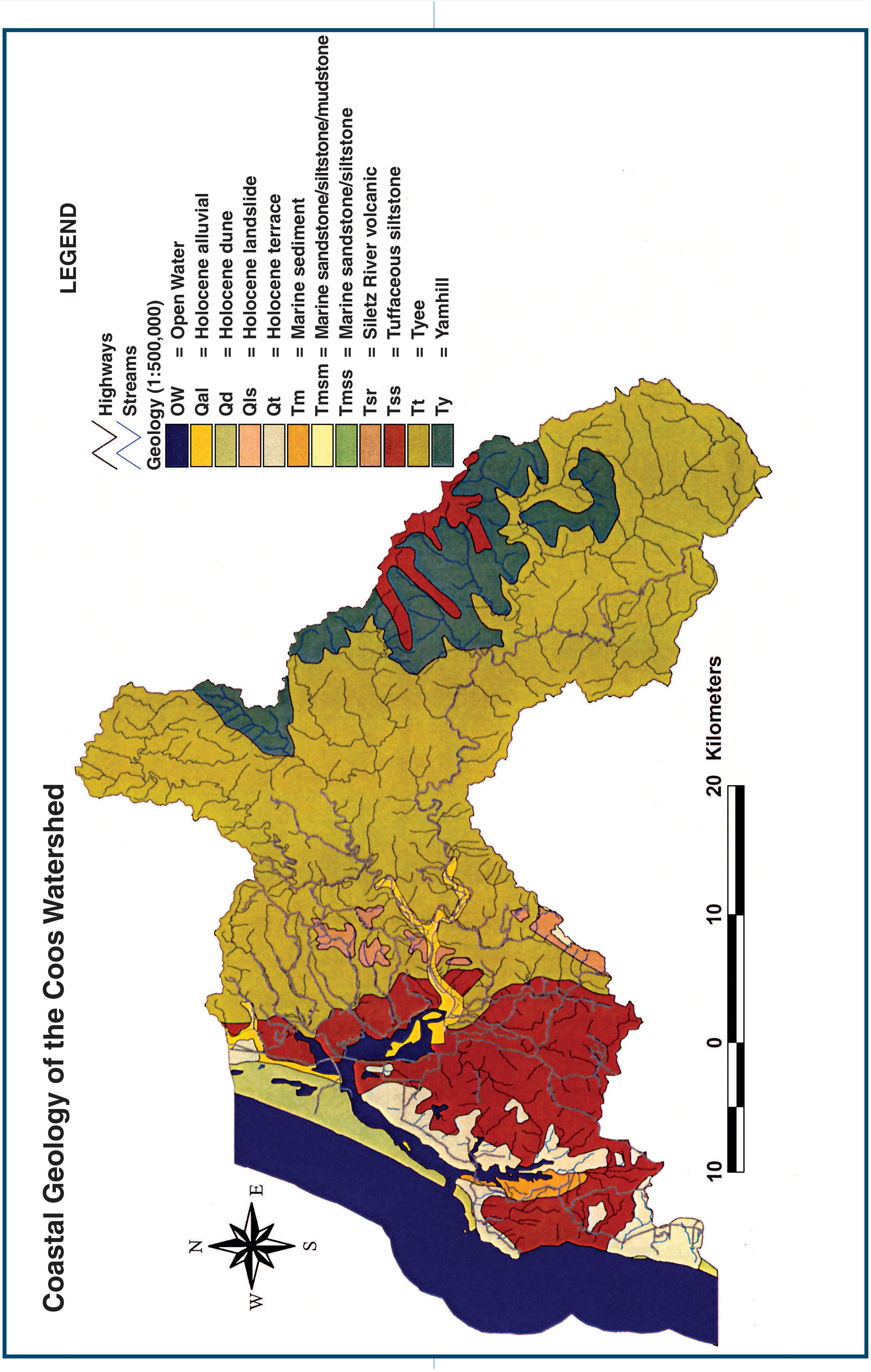


Figure 1.22. Coastal geology of the Coos watershed (from Madin *et al*., 1995).

range from –8 °C to 38 °C, but more typical temperatures range between 6-16 °C. Average annual snowfall is from 2-6 cm, and dense fog occurs about 43 days per year. Prevailing winds blow from the north during the summer at an average velocity of about 27 kmh^{-1} (see Figure 1.7). In winter, the wind direction generally swings to the south and southwest at an average velocity of about 24 kmh^{-1}. The Coos estuary is exposed to the full force of ocean storms, and winds can reach hurricane speed (sustained velocities greater than 120 kmh^{-1} with gusts over 200 kmh^{-1}). Severe storms sometimes occur during the winter (November through March) from the northwest, and can generate 4 m waves in the mouth of the estuary. The open water of the Coos estuary typically has a ground swell of 0.5 m, and white-caps and light chop conditions are common.

1.3.1.c Geology of the Coos Estuary Basin

Tidal waters of the Coos estuary are contained largely within a deltaic sedimentary basin of late Eocene Coaledo Formation bedrock (Figure 1.22). Claystone, siltstone, and cross-bedded sandstone layers that make up the Coledo Formation occur in sequence along with other sedimentary rocks in the lower reaches of the estuary, and in several rocky outcrops that occur near the estuary mouth and above the end of the navigation channel (Figure 1.23). The oldest layer is a cross-bedded tuffaceous claystone mixed with conglomerate mudstone pebbles. The thin-bedded siltstone (middle) layer was formed by deposition in deep ocean water during the maximum transgression of the sea, probably as much as 180 m below present sea level. The upper

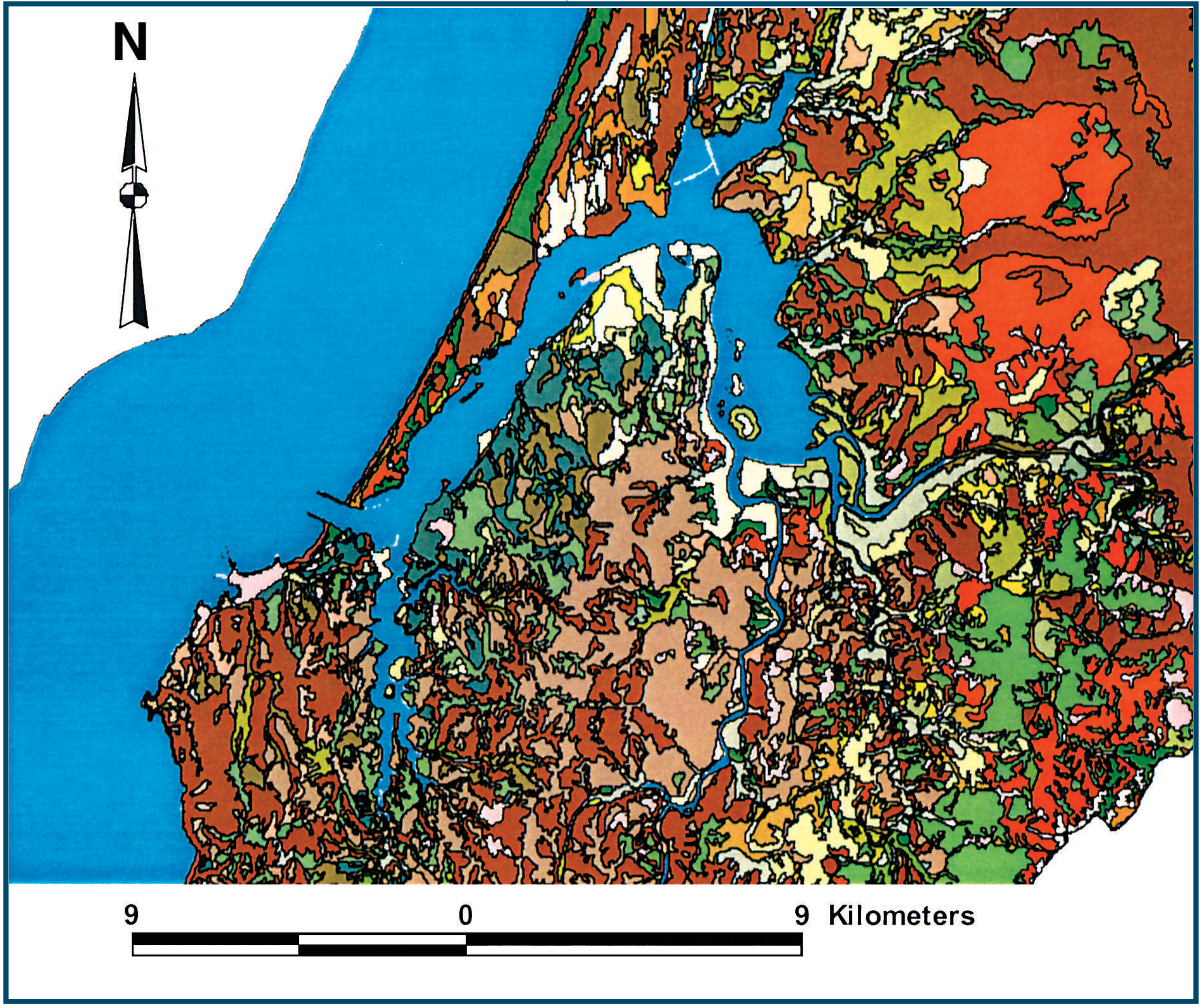


Figure 1.23. Surface soils in the vicinity of the Coos estuary and South Slough, OR (from Haagen, 1989). Sediments exposed on the low hills of the Coos watershed are primarily soft loamy soils of the Templeton-Salander group, and sandy marine terraces of the Bullards-Bandon-Blacklock group. Soils exposed on the steep eastern hillsides are primarily deep gravel and loam soils of the Preacher-Bohannon group.

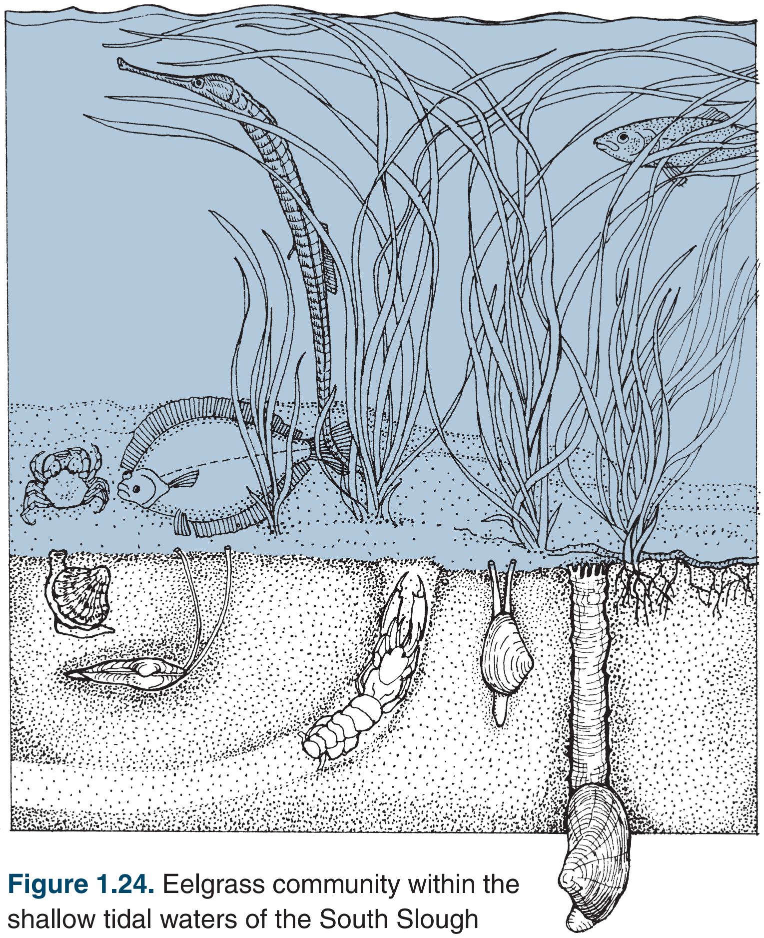


Figure 1.24. Eelgrass community within the shallow tidal waters of the South Slough estuary. Burrowing clams and shrimp inhabit the soft-sediment mudflats, while crabs, flounder, and pipefish forage among the blades of the eelgrass canopy. Illustration by Sharon Torvik.

layer is a coarse to fine-grained sandstone with poorly rounded mudstone blocks. The Coledo Formation layers are severely deformed and overlaid by younger strata including the fine-grained Bastendorf Formation shales (late Eocene), sandy Miocene fossil beds, and Empire Foundation sandstones (Pliocene). Sediments in the estuarine tidal channel vary from coarse-grained sand in the lower estuary to fine-grained sand and silts in the upper channel. Landforms surrounding most of the shoreline of the Coos estuary are composed primarily of uplifted Quaternary marine terraces capped with marine deposits.

1.3.2 Biotic Resources of the Coos Estuary

The Coos estuary encompasses several different types of habitats that support a wide variety of living marine and estuarine communities (Miller *et al.*, 1990). The lower marine-dominated region of the estuary extends from the ocean jetties upstream about 16 km (River Mile 10) to the city of North Bend. Bedrock, sand, and muddy substrata are colonized by diverse communities of benthic macroalgae (including *Nereocyctis, Fucus, Egregia, Desmarestia, Gigartina, Ulva, Enteromorpha, Chaetomorpha*), eelgrass beds (*Zostera marina, Z. japonica*), and emergent salt marshes (*Carex, Salicornia, Distichlus, Triglochin*). The expansive tideflats are inhabited by burrowing bivalves including gaper clams (*Tresus capax*), cockles (*Clinocardium nuttallii*), littleneck clams (*Protothaca staminea*), and softshell clams (*Mya arenaria*), and by burrowing shrimp (*Neotrypaea califoriensis, Upogebia pugettensis*; Figure 1.24). Deeper waters and shell rubble habitats are inhabited by crabs (*Cancer magister, C. productus*), shrimp (*Heptacarpus, Betaeus, Crangon*) and diverse assemblages of fish (kelp greenling, black rockfish, sand lance, sand dabs, staghorn sculpin, starry flounder, English sole, Pacific herring, smelt, northern anchovy, surf perch, pile perch). The water column is dominated by copepods and marine diatoms (*e.g. Chaetoceros, Skeletonema, Thalassiosira*).

The middle region of the Coos estuary (from North Bend to the southern end of Bull Island / 29 km (RM 18)) is an important transition zone where the saline tidal waters mix with freshwater from the rivers, streams, and sloughs. The substratum within this depositional area is predominantly soft mud mixed with significant amounts of terrestrial materials and log debris. The extensive tideflats and drainage channels are inhabited by diverse assemblages of predatory, suspension-feeding and deposit-feeding polychaetes (*i.e., Nereis, Streblospio, Ophelia, Glycera, Heteromastis, Abarenicola, Polydora*). In addition, oligochaetes, cumaceans, burrowing amphipods (*Corophium*), and several species of bivalves (*Mya, Cryptomya, Tellina, Macoma* spp.) are also common (Jones, 1990). Substantial but patchy eelgrass beds occur within the intertidal areas and along the edges of the tidal channels, and significant expanses of emergent salt marshes occur in the tidal inlets and sloughs. This middle region of the estuary has undergone significant alteration over the past century. Dredge and fill operations were carried out to create flatlands for municipal development, and dike and drain activities allowed agriculture and dairy farms to prosper along the shoreline. These large-scale alterations of the estuarine habitat contributed to a

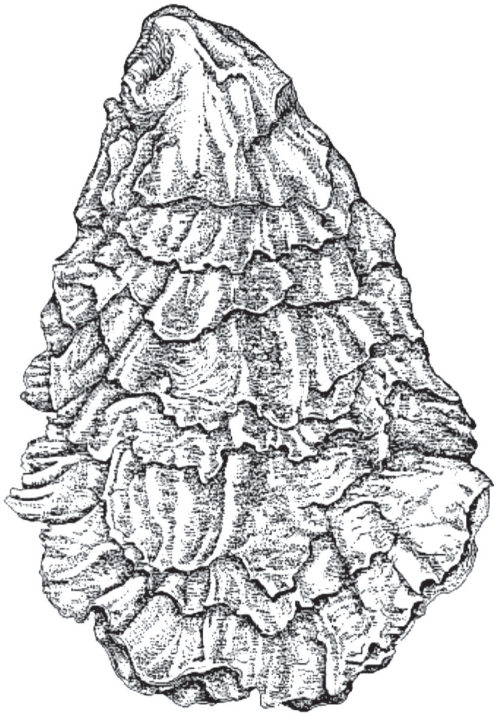


Figure 1.25. The Pacific oyster (*Crassostrea gigas*) is cultivated commercially in South Slough.

25% loss in the overall spatial extent of the Coos estuary between the 1890's and 2000, and to 85% loss of emergent tidal wetlands (Hoffnagle and Olson, 1974; Good, 2000). In recent years, the Coos estuary has experienced a slight but steady increase in the spatial extent of tidal marshes due to colonization of dredge spoils islands and shoreline restoration activities (Rumrill and Cornu, 1995; Shaeffer, 1998).

The riverine region of the Coos estuary extends from Bull Island (29 km / RM 18) up the Millicoma River to the head of tide at Allegeny (45 km) and up the Coos River to Dellwood (38 km). These riverine waters provide an important migratory corridor for several species of anadromous fish (coho, chinook, chum salmon, steelhead, searun cutthroat trout), and year-round habitat for striped bass, green and white sturgeon, and perch (ACOE, 1993). Tidally-driven transport of marine and estuarine plants (eelgrass and algae) is evident within the riverine channels, and they provide a pathway for the transport of logs, root wads, and large woody debris downstream from sources further upstream in the Coos watershed. The slow-moving waters and shoreline of the riverine region are an important habitat for river otters, great blue heron, raccoon, and beaver.

Commercial cultivation of oysters (*Crassostrea gigas* and *C. virginica*) has occurred within the Coos estuary since the 1920's. Growout plots for Pacific oysters (*C. gigas*) are a conspicuous and dominant feature of the exposed tideflats, particularly in the region near North Inlet and within the South Slough (Figure 1.25). The Coos estuary is the largest producer of Pacific oysters in Oregon with annual production valued at $2.8 M in 1995 and nearly $3.5 M in 1999. The majority of oysters are cultured directly on the muddy-sand substratum for growout periods of 2-3 years (ground culture), although oysters are also cultivated above the bottom on stakes in the South Slough. Native Olympia oysters (*Ostrea conchaphila*) were once abundant in the Coos estuary but became locally extinct prior to written history due to a basin-wide change in sedimentation (Dall, 1897; Stubbs, 1973). Discontinuous populations of *O. conchaphila* have become reestablished in the shallow subtidal zone over the past decade (Baker *et al.,* 2000).

The Coos estuary has been colonized by over 70 aquatic non-indigenous species and another 20 species that are cryptogenic in origin (Carlton, 1989; Hewitt, 1993; Carlton, 2001). The assemblage of non-native estuarine organisms includes over 20 species of crustaceans, 9 polychaetes, 8 bryozoans, 7 molluscs, 7 coelenterates, and 5 urochordates, and representatives from many other taxonomic groups. Tidal habitats within the middle region of the Coos estuary are particularly susceptible to colonization by non-indigenous species (Figure 1.26). Between 40-80% of

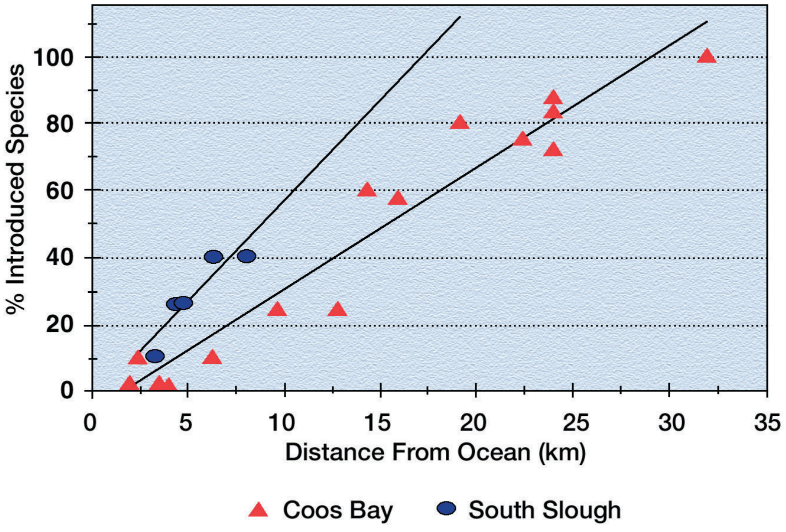


Figure 1.26. Proportion of estuarine invertebrate community contributed to Coos Bay and the South Slough by introduced species as a function of distance from the ocean (from Hewitt, 1993).

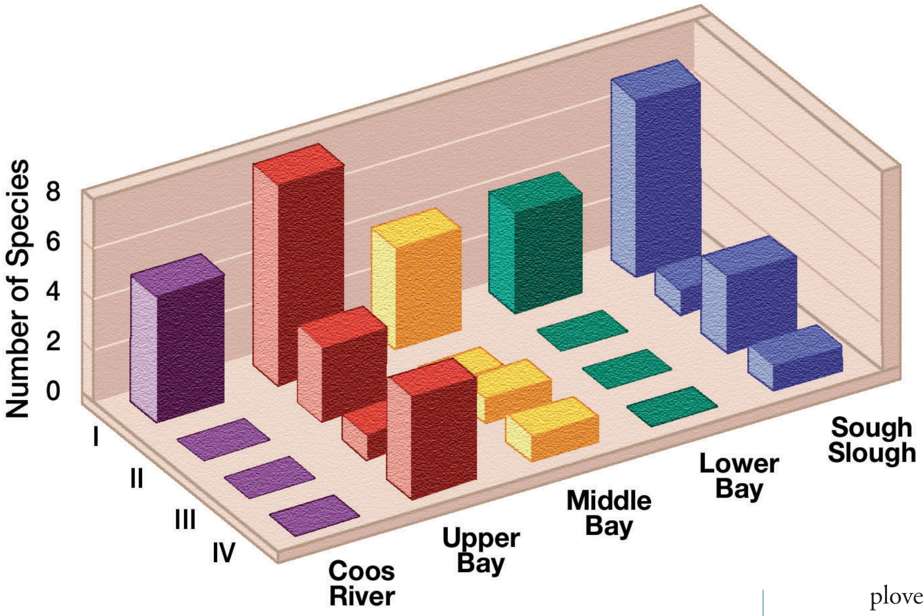


Figure 1.27. Abundance of introduced invertebrates in five regions of Coos Bay according to their affinities with specific introduction vectors: I= Wooden hulled vessel fouling, II=Atlantic oyster culture, III=Pacific oyster culture, IV=Modern introduction mechanisms (from Hewitt, 1993).

the estuarine species assemblage was composed of native species in the marine-dominated region of the estuary (0-8 km) in 1991. In contrast, 60-90% of the species were non-natives in the transitional region located 15-25 km from the ocean jetties (Hewitt, 1993). These non-indigenous species have been introduced into the Coos estuary since the 1850's by 4 primary transport mechanisms (Figure 1.27): (I) biofouling on wooden ship hulls; (II) commercial mariculture of Atlantic oysters (*Crassostrea virginica*); (III) commercial culture of Pacific oysters (*C. gigas*); and (IV) modern vectors including ballast water transport, intentional plantings of new mariculture species, and inter-estuarine exchange via small boats (Hewitt, 1993). In addition, recent arrivals such as the European green crab (*Carcinus maenas*) were initially introduced in association with the mariculture industry, but they have persisted by the subsequent input of planktonic larvae (Yamada *et al.,* 2000; Yamada, 2002).

The Coos estuary is an important resting, feeding area, and wintering ground for migratory birds of the Pacific flyway. About 250 species of birds are either resident inhabitants or migratory visitors to the tidal waters and shoreline of the Coos estuary (ACOE, 1993). These include a variety of waterfowl (*i.e.,* American wigeon, black brant, pintail, canvasback, bufflehead, scaup, western grebe, surf scoter), shorebirds (western sandpiper, least sandpiper, sanderling, black-bellied plover), seabirds (gulls, common murres, pigeon guillemot, brandt's cormorant, pelagic cormorant, brown pelican), and raptors (marsh hawk, osprey, bald eagle). American crow, belted kingfisher, and great blue heron are also commonly observed along the shoreline and in the exposed tideflats (Figure 1.28).

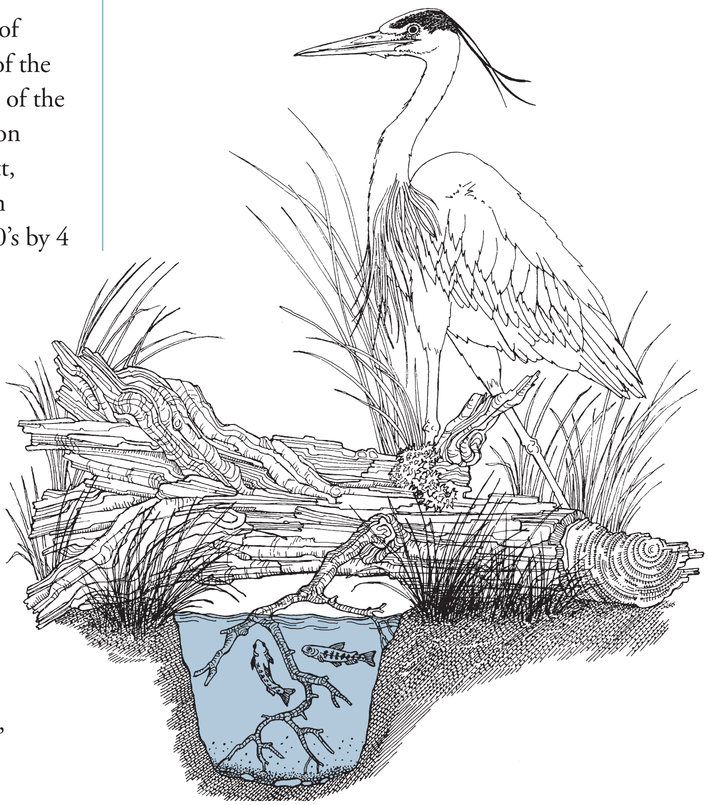


Figure 1.28. Great blue herons (*Ardea herodias*) are commonly observed around the shoreline of the South Slough estuary where they hunt for fish, invertebrates, and aquatic insects in tidal creeks and channels. Illustration by Sharon Torvik.

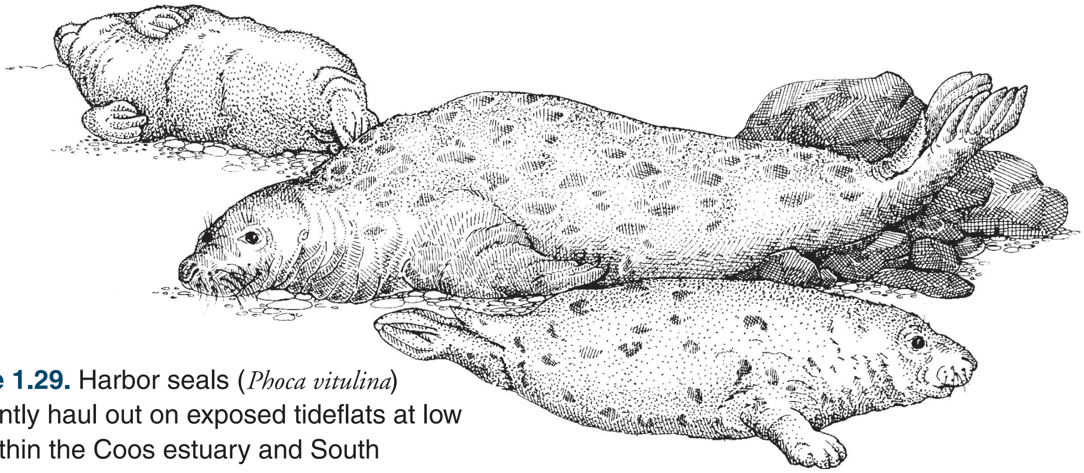


Figure 1.29. Harbor seals (*Phoca vitulina*) frequently haul out on exposed tideflats at low tide within the Coos estuary and South Slough. Illustration by Sharon Torvik.

Several species of marine mammals are temporary residents of the Coos estuary where they enter the tidal waters to explore, feed and rest. Harbor seals (*Phoca vitulina*) prey upon resident estuarine fish and haul out in large numbers on the exposed tideflats in the lower region of the Coos estuary and in South Slough (Figure 1.29). California sea lions (*Zalophus californianus*) are common near the docks and marinas, and Steller sea lions (*Eumetopias jubatus*) frequently forage in the estuary from their haul out sites at nearby Cape Arago. Juvenile northern elephant seals (*Mirounga angustirostris*), orca (*Orcinus orca*), harbor porpoise (P*hocoena phocoena*), and gray whales (*Eschrichtius robustus*) are occasional visitors to the Coos estuary.

1.4 South Slough Watershed and the South Slough National Estuarine Research Reserve

The South Slough watershed sub-basin terminates in one of ten shallow tidal inlets that drain into the Coos estuary. As the southernmost of these tidal marine and freshwater systems, the South Slough is unique because the mouth of the inlet merges with the Coos estuary near its opening and confluence with the Pacific Ocean (Figure 1.30). Consequently, the South Slough estuary encompasses the entire environmental gradient from the marine-dominated channels and tideflats in the northern region, through the mesohaline estuarine mixing zone at the mid region, to the riverine and freshwater habitats at the southern end of the drainage system.

1.4.1 South Slough Watershed and Estuary

The South Slough watershed has considerable significance as a relatively undisturbed representative of Lower Columbian coastal ecosystems. The South Slough watershed is a 7,935 ha (19,600 ac) sub-basin of the Coos watershed drainage system. The watershed encompasses a diversity of habitat components including: (a) a drowned river-mouth estuary with open water channels, tidal flats, and salt marshes, (b) a mixture of palustrine and forested freshwater wetlands, streams, and riparian areas, and (c) coastal Sitka spruce and western hemlock forests with mixed-age stands of coniferous and deciduous trees and lush understory vegetation. The steep coastal South Slough watershed catchment basin is a distinct hydrologic unit with numerous perennial and intermittent streams, and the drainage system has considerable topographic relief with ridgelines and elevated terraces at 90 m above sea level (Figure 1.31). Approximately 70% of the watershed is in private or county ownership and the land parcels are actively managed for the production of timber, 5% of the watershed is zoned for rural residential occupation, and the remaining parcel (24%; 4,771 acres) is encompassed by the administrative boundaries of the South Slough National Estuarine Research Reserve

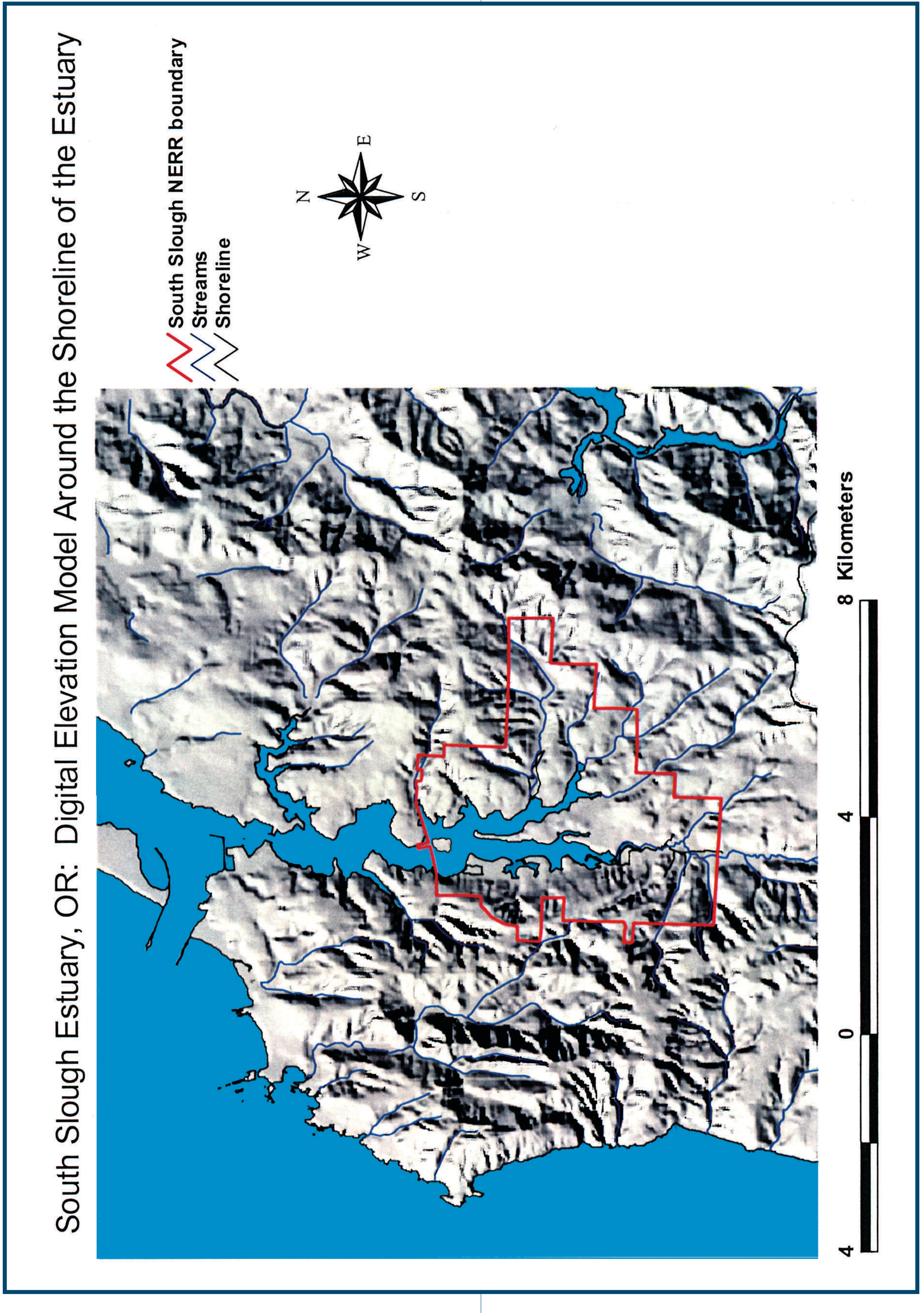


Figure 1.30. South Slough estuary, OR: Shaded relief Digital Elevation Model around the shoreline of the estuary. Topographic range 0-200m.

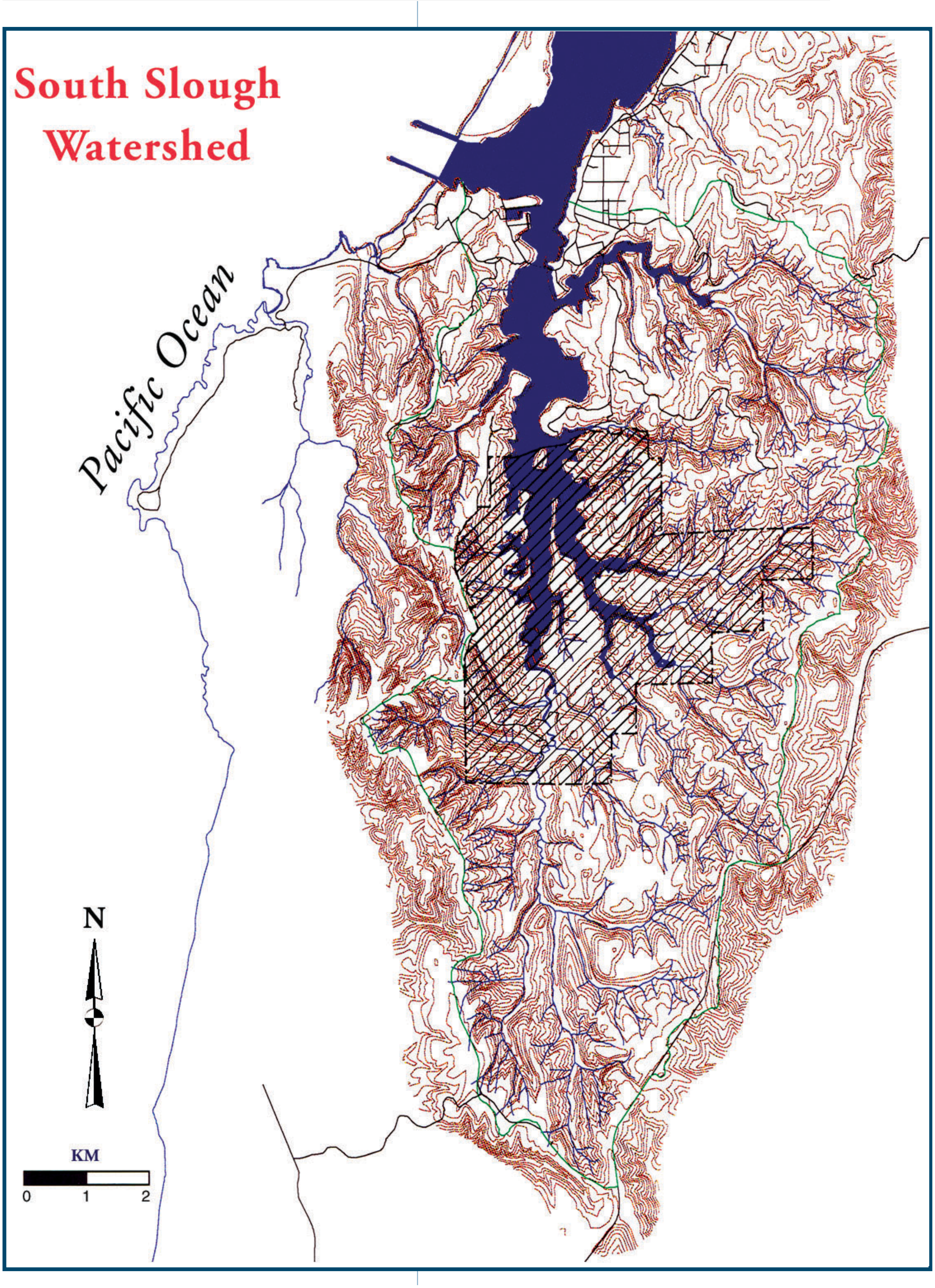


Figure 1.31. South Slough watershed. The South Slough watershed is a distinct sub-basin of the Coos watershed (contour interval 40 ft.).

(Figure 1.32). Tidal components of the South Slough watershed are directly connected through a narrow mouth (near Charleston) to the greater Coos estuary, and the drainage system is ecologically important in its capacity to integrate influences of natural process and human disturbances within the context of the linked habitat components of a coastal land-margin ecosystem.

Land Ownership and Uses in South Slough Watershed

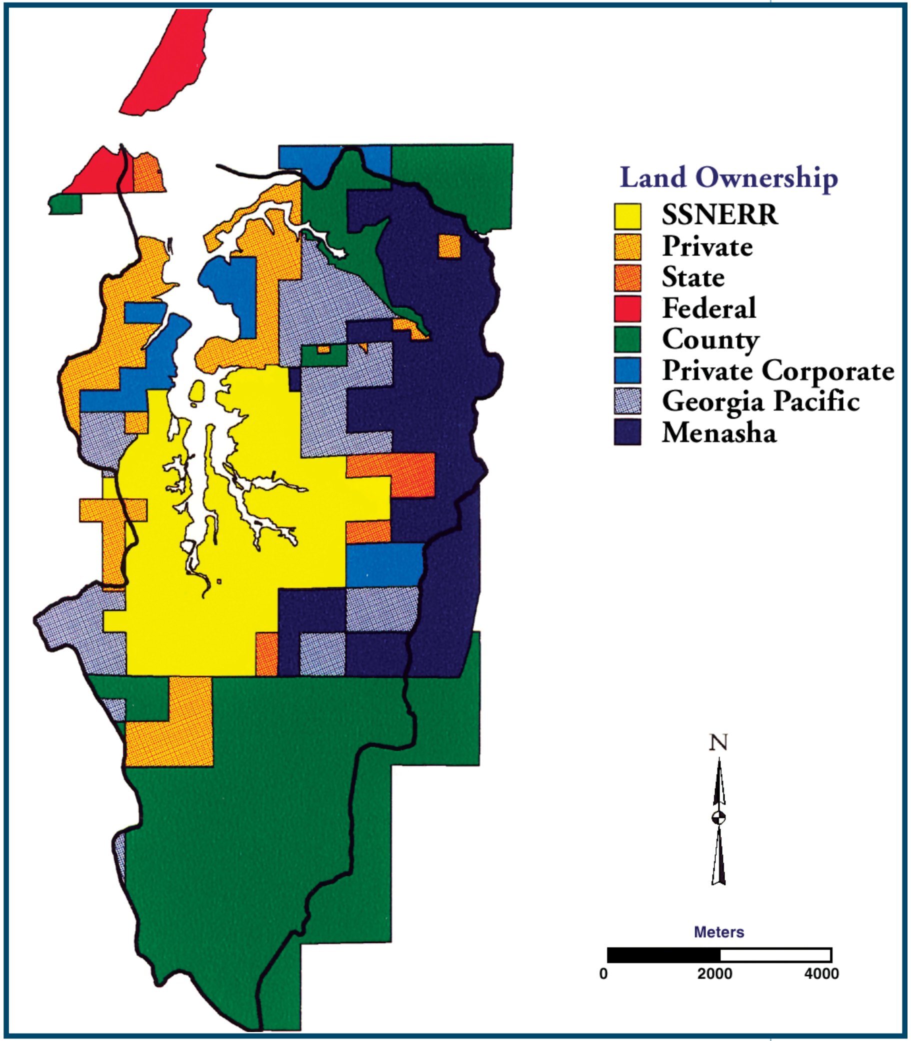
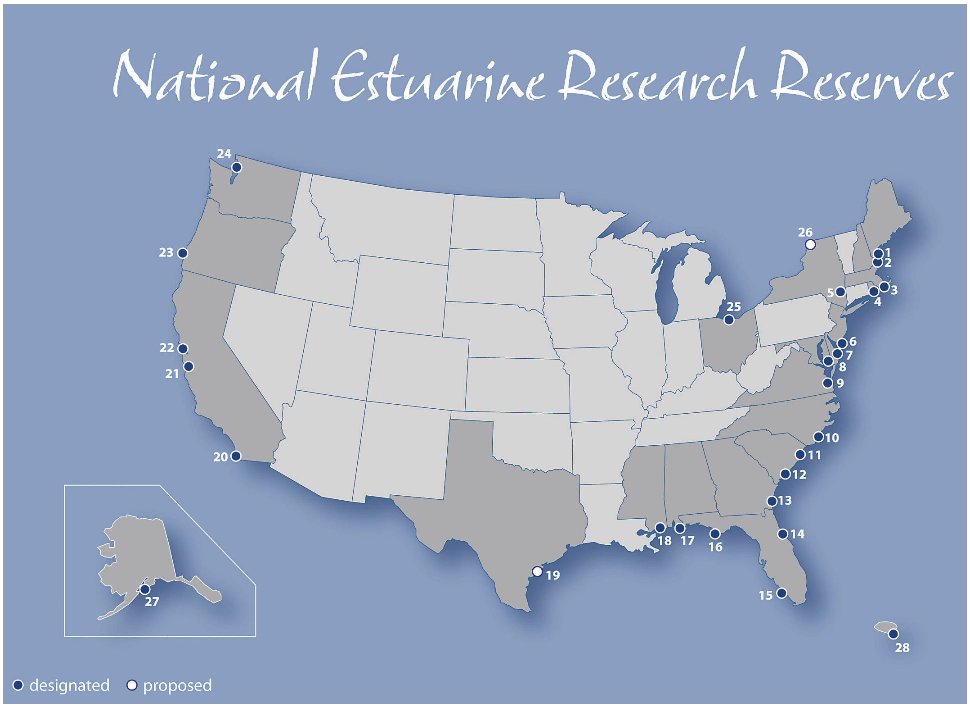


Figure 1.32. Land ownership and land use classes in the South Slough watershed (1995).

1.4.2 Recognition and Designation as a National Estuarine Research Reserve

The National Estuarine Research Reserve System (NERRS) was authorized by Section 315 of the Coastal Zone Management Act (1972) to support development of federal-state partnership programs that focus on investigations and understandings of natural and anthropogenic processes within estuaries and coastal embayments. The current system includes 26 designated and 2 proposed Reserves that are representative of estuarine ecosystems throughout the United States and its territories (Figure 1.33). Each Reserve has been selected as a natural laboratory to sustain a wide variety of beneficial ecological, economic, recreational, and aesthetic values which are dependent upon maintenance of healthy estuarine ecosystems. Individual Reserve sites provide critical habitat for ecologically and commercially important species of fish, shellfish, birds, and other aquatic and terrestrial wildlife. Moreover, each Reserve has been designated to function as a distinct conservation unit including the preservation of core tideland communities surrounded by adjacent buffer zones, and they are afforded sufficient protection to ensure their integrity as sites for long-term monitoring and research. As part of a national system, the NERRs sites collectively provide exceptional opportunities to address research questions and estuarine management issues of national significance. The NERR system also provides an institutional framework through which research results and techniques for estuarine education and interpretation can be shared throughout biogeographic regions and across the nation.

The existing NERR system provides management services for over 469,900 ha of estuarine waters, wetlands, and upland habitats. The Reserve sites are united by a common mission: *to promote informed management and stewardship of the Nation's estuarine and coastal habitats through scientific understanding linked with public education.*



1. Wells Reserve, Maine
2. Great Bay Reserve, New Hampshire
3. Waquoit Bay Reserve, Massachusetts
4. Narragansett Bay Reserve, Rhode Island
5. Hudson River Reserve, New York
6. Jacques Cousteau Reserve, New Jersey
7. Delaware Reserve
8. Chesapeake Bay Reserve, Maryland
9. Chesapeake Bay Reserve, Virginia
10. North Carolina Reserve
11. North Inlet-Winyah Bay Reserve, South Carolina
12. ACE Basin Reserve, South Carolina
13. Sapelo Island, Georgia
14. Guana Tolomato Matanzas Reserve, Florida
15. Rookery Bay Reserve, Florida
16. Apalachicola Reserve, Florida
17. Weeks Bay Reserve, Alabama
18. Grand Bay Reserve, Mississippi
19. Proposed Reserve—Texas
20. Tijuana River Reserve, California
21. Elkhorn Slough Reserve, California
22. San Francisco Bay, California
23. South Slough Reserve, Oregon
24. Padilla Bay Reserve, Washington
25. Old Woman Creek, Ohio
26. Proposed Reserve—St. Lawrence River
27. Kachemak Bay Reserve, Alaska
28. Jobos Bay Reserve, Puerto Rico

Figure 1.33. Map of the National Estuarine Research Reserve System. The current system includes 26 designated and 2 proposed Reserves that are representative of estuarine ecosystems throughout the United States and its territories.

State and Federal partners take progressive steps in support of this mission by fulfillment of the following goals (NOAA, 1995):

(a) **Representative Protected Areas:** establishment and management of a national network of protected areas that represent diverse biogeographic and typologic estuarine ecosystems;

(b) **Partnerships:** mobilization of federal, state, and community resources to mutually define and achieve coastal protection and management goals and objectives;

(c) **Informed Management and Stewardship:** operate the NERR system as a national program contributing to informed, integrated management of the Nation's coastal ecosystems;

(d) **Scientific Understanding Through Research:** design and implement a comprehensive program of scientific research to address coastal management issues and their fundamental underlying processes; and

(e) **Education:** design and implement a comprehensive program of education and interpretation based on solid scientific principles to strengthen the understanding, appreciation, and stewardship of estuaries, coastal habitats, and associated watersheds.

Estuarine tidal channels, marshes, and forest components encompassed by the South Slough watershed were the first elements of an estuarine ecosystem offered permanent protection under Section 315 of the Coastal Zone Management Act of 1972 (Pub. Law 92-583). Significant portions of the South Slough estuary and watershed were initially recognized as the South Slough National Estuarine Sanctuary (NES) in 1974. The Oregon Legislature enacted HB 3269 (1977) to authorize the state of Oregon Land Board to acquire and accept the dedication of public and privately-owned lands for the creation of the South Slough NES. Designation of the South Slough NES provided the Oregon Land Board (acting through the South Slough NES Management Commission and the Oregon Division of State Lands) with statutory authority to manage and protect the lands for existing and traditional uses as well as for the purposes of education, scientific research, and low-intensity recreation (SSNES, 1984; SSNERR, 1994). South Slough NES was formally renamed the South Slough National Estuarine Research Reserve (NERR) in 1992 by adoption of federal reauthorization amendments to the Coastal Zone Management Act of 1990 (Federal Register, 1993). The Reserve has been jointly operated over the past 27 years by the National Oceanographic and Atmospheric Administration (NOAA) and the Oregon Department of State Lands. NOAA's mission includes management of the nation's coastal resources, and promotion of global stewardship of the world's oceans and atmosphere through science and service. The Oregon Department of State Lands administers and manages state-owned properties and resources to generate and contribute funds toward operation of public schools.

1.4.3 South Slough National Estuarine Research Reserve

The South Slough NERR is located about 3 km east of Cape Arago and 5 km southwest of the city of Coos Bay, OR. The Reserve operates along the southern Oregon coast as a dedicated site for long-term monitoring and scientific investigations with direct applications toward improvements in coastal zone management. South Slough NERR has gained recognition as an integrated system of land-margin habitats that can provide important reference information regarding ecological relationships among coastal ecotones and adjacent habitat patches. The Coos estuary and South Slough drainage basin provides a representative example of a Pacific northwest coastal ecosystem that integrates functional processes within upland forests and commercial timberlands, coastal streams and riparian areas, estuarine tidelands, and nearshore marine regions (Figure 1.34). These distinct landscape features comprise a series of linked land-margin habitats that are particularly well suited to interdisciplinary research aimed at understanding large-scale patterns and processes that contribute to a healthy coastal ecosystem. In addition, South Slough NERR serves an equally valuable function as a natural laboratory for testing empirical hypotheses and assessment protocol for evaluating existing and new paradigms in coastal ecosystem management. These related functions: (a) natural resource management, (b) scientific research, (c) long-term monitoring, and (d) public outreach and education, establish a mandate for management of the research / natural area.

1.4.3.a Estuarine Typology and Habitat Description

The South Slough NERR was selected as a representative coastal watershed / estuarine habitat within the Lower Columbia Bioregion (Table 1.2). A variety of estuarine ecosystem typologies are encompassed by the South Slough NERR including: (a) maritime temperate coniferous forest shorelands and coastal cliffs, (b) transitional areas consisting of coastal marshes, intertidal sand and mudflats, and intertidal algal beds, and (c) submerged channel bottoms with a mixture of hard and soft substrata and submerged aquatic vegetation. The physical typological characteristics include: (d) a sheltered and protected tidal river, (e) a drowned river mouth basin structure, (f) a permanent and restricted tidal inlet, and (g) substrata consisting of sand, mud, rock, and oyster shell. Other hydrologic and chemical typologic characteristics include: (h) stratified semidiurnal tidal circulation, and (i) a positive estuary with a full salinity range and a circumneutral pH regime (Table 1.2).

Table 1.2 Estuarine typology for the South Slough NERR, OR. NOAA typology according to FR/Vol. 58, No. 134 (1993)

CLASS I — ECOSYSTEM TYPES

Group I – Shorelands
- A. Maritime Forest – Woodland (2. Moist temperate coniferous forest biome)
- E. Coastal Cliffs

Group II – Transition Areas
- A. Coastal marshes (a. tidal; b. nontidal (freshwater); c. tidal freshwater)
- E. Intertidal Mud and Sandflats
- F. Intertidal Algal Beds

Group III – Submerged Bottoms
- A. Subtidal Hardbottoms
- B. Subtidal Softbottoms
- C. Subtidal Plants

CLASS II— PHYSICAL CHARACTERISTICS

Group I – Geologic
- A. Basin Type (2. Sheltered Coast; 4. Embayment; 5. Tidal River)
- B. Basin Structure (Drowned River Mouth Estuary; 1. Coastal Plain)
- C. Inlet Type (2. Restricted; 3 Permanent)
- D. Bottom Composition (1. Sand; 2. Mud; 3. Rock; 4. Oyster Shell)

Group II – Hydrologic
- A. Circulation (1. Stratified)
- B. Tides (2. Semidiurnal)
- C. Freshwater (1. Surface Water; 2. Subsurface Water; b. Groundwater)

Group III – Chemical
- A. Salinity (1. Positive Estuary; 3. Salinity Zone c. mixohaline 30 - 0.5 ppt) (Note: SSNERR - polyhaline, mesohaline, oligohaline, and limnetic)
- B. pH Regime (2. Circumneutral pH rages from 5.5 to 7.4)

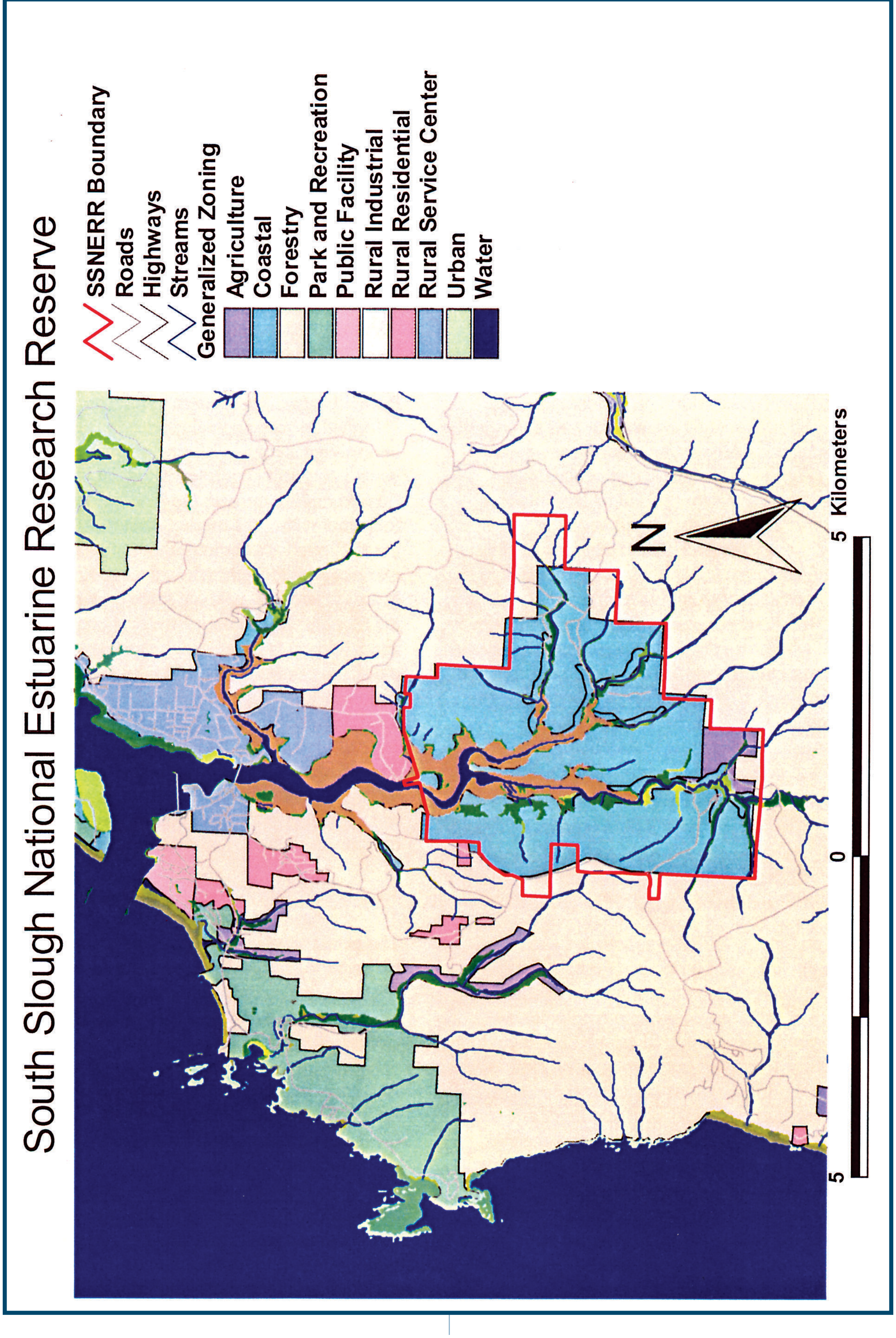


Figure 1.34. South Slough National Estuarine Research Reserve, OR. The South Slough NERR encompasses 1934 ha (4,779 ac) within the coastal watershed. Tidal components of the South Slough are directly connected to the Coos estuary and the Pacific Ocean.

The South Slough is a sheltered arm of the Coos estuary that is joined in the north by Joe Ney Slough and bisected in the southern region by a long riparian peninsula into two narrow tidal waterways (Winchester Arm and Sengstacken Arm; see Figure 1.31). The South Slough is about 9 km long with an average width of about 600 m. Salinities in the northern marine-dominated region are generally high due to direct tidal access and the close proximity of the slough to the mouth of the Coos estuary and the Pacific Ocean. Freshwater input from upland areas is limited to six principal creeks and several intermittent streams. Mixing of fresh and saline water is typically complete and tidal waters are flushed rapidly through the 2 million m^3 slough. Substrata within the marine-dominated region of the South Slough are composed of a mixture of coarse marine sands and silt, while finer sediments rich in organic materials make up more protected parts of the Slough. The estuarine basin is composed of about 222 ha of intertidal lands consisting of mudflats, eelgrass beds, and tidal marshes, and approximately 16 ha of subtidal channels. Tidal habitats within the South Slough NERR are bounded on their upstream sides by a series of freshwater streams and riparian corridors that transgress into a mosaic of upland forest habitats including maturing stands of conifers and deciduous trees (>70 years old), brushy hillsides, and recovering clearcuts.

1.4.3.b Primary Reserve Mission and Programs

The primary mission of the South Slough NERR is to: *improve the understanding and stewardship of Pacific northwest estuaries and coastal watersheds.*

The South Slough NERR takes active steps toward this mission by conducting long-term estuarine research, monitoring, education, interpretation, and resource stewardship programs with particular emphasis on estuaries and coastal watershed ecosystems located within the Lower Columbia biogeographic region.

Activities and programs are carried out by the South Slough NERR to address five cardinal goals: (a) *Reserve Administration* / to manage operations of the Reserve within the statutory framework of federal and state partner agencies, provide leadership for efficient financial oversight, ensure work and training by professional staff members, and create opportunities for public participation to increase the operational capacity of the Reserve; (b) *Facilities and Public Access* / to provide for safe and efficient buildings, facilities and public access with techniques that are innovative and environmentally responsible; (c) *Research and Monitoring* / to conduct and coordinate scientific research that contributes to increased understanding of Pacific northwest estuaries, assess and monitor the status of estuarine habitats and biotic indicators, and provide technical assistance and advisory services that contribute to effective coastal zone management; (d) *Education and Outreach* / to develop and deliver education programs and activities for academic audiences, develop and maintain education and interpretive programs and exhibits that serve multiple audiences, and promote awareness and stewardship of estuaries within local communities; and (e) *Stewardship and Habitat Restoration* / to manage and restore habitats and ecosystem processes within the Reserve, test and demonstrate stewardship practices and innovative land management strategies, and participate along with regional and national resource management agencies to address estuarine and coastal watershed issues, resource planning, and disaster response activities.

1.4.3.c Historical and Cultural Resources

The shoreline of the South Slough estuary has probably been inhabited for about 5,000 years. Human occupation of the protected shoreline became feasible following stabilization of the Pacific northwest coast at the end of the ice age (Pullen, 1995), and small groups of native Americans hunted marine mammals, elk, and deer in the warmer and drier climate. Artifacts recovered from these early indigenous residents include stone spear points, flaked stone knives, and stone bowls used to grind seeds and roots. Regional environmental conditions changed about 2,500 years ago with increased rainfall, growth of dense coastal coniferous forests, and rapid increases in the productivity of the estuary. Small villages and seasonal encampments located along the South Slough were occupied beginning in about 500 AD by the Miluk people. The Miluk villages were year-round and nearly autonomous gatherings of about 100 people, and the pole-frame lodge structures were either covered with thatch matting or split cedar planks. Native peoples used cedar dugout canoes to travel and collect food along the banks of the estuary, and thick shell middens provide evidence that the estuary was a productive place to collect littleneck and gaper clams, cockles, crabs and other shellfish (Pullen, 1995). Wooden fish weirs were built to trap salmon and smelt on falling tides, and several remnant weirs have been located in the muddy shallow tidelands. The Miluk also caught perch and flounder with antler hooks, and they hunted elk and deer, gathered salal berries, and harvested roots and other plants from the forest. The meandering estuary and low bottomlands of the South Slough provided an avenue for the passage of native people from the Coos estuary to the adjacent Coquille drainage system to the south, and the Miluk name for the South Slough was *"Wit-litz"* (where one goes over the hill or divide; Caldera, 1995). The Hanis people lived in the northern part of Coos estuary and called the South Slough *"Yah-ai-kim-kitch"* (the other creek) in reference to the historic northern location where the Coos estuary exited to the Pacific Ocean through a breach in the North Spit (Caldera, 1995).

Euro-American fur trappers and other explorers first visited the Coos and South Slough estuaries in the early 1800's. By then the Miluk and Hanis societies were well organized, although the tribal villagers had developed only rudimentary trading connections and commerce with the larger Umpqua, Willamette and Klamath regions. The Lewis and Clark expedition camped near the mouth of the Columbia River in 1805-06, and their journals noted that the region around the Coos estuary was occupied at that time by a nation of about 1,500 people. The first team of explorers from the Hudson's Bay Company (led by Alexander McLeod) traveled from the north to the mouth of the Coos estuary in October of 1826, and they made their way up the South Slough by canoe. Members of the Jedediah Smith expedition traveled from the south by horseback and camped near the Miluk village at the mouth of the South Slough in the summer of 1828. Epidemics of smallpox and malaria decimated the Miluk and Hanis people in the 1830's, and the surviving Indians were weakened, dispirited, and poor. The first Euro-American settlers established a tent village in 1853 along the shoreline of the Coos estuary after the wreck of the transport ship *Captain Lincoln*, and miners traveled extensively through the South Slough to prospect for gold in the 1850's. The 1850's were also marked by several conflicts, murder, and retaliatory massacres, and in 1855 the Miluk people were gathered by American soldiers and deported north to a reservation at Yachats. Several Miluk people escaped from the reservation and returned to the South Slough to establish permanent residences in the 1860's.

Logging operations began in the South Slough watershed in the late 1850's, and a waterwheel sawmill was constructed on Winchester Creek in 1860. The Smith-Powers logging camp and railroad were established in 1906 to transport lumber, and logs were often pulled to the shoreline by teams of oxen and floated out of the estuary on the tides (Figure 1.35). The last log raft was towed by tugboat out of the South Slough in the late 1950's, although road-based logging operations continue up to the present in the South Slough watershed. Following the onset of Euro-American settlement and the end of hostilities, a number of the original families were permitted to claim homesites in the 1870's along the shore of the South Slough and its tributaries. Over 20 families settled in the South Slough basin by the early 1870's, and many of the creeks and landmarks reflect the names of the early settlers (Collver, Day, Elliott, Hanson, Hayward, Hinch, Rhodes, Talbot, Wasson, Winchester, Younker). A large forest fire swept through the South Slough in 1874. Shortly thereafter, a series of small houses, barns, windmills, a schoolhouse, and other structures were constructed in the valleys, coves and low hills of the South Slough drainage basin from the late 1880's until the 1920's. Resident families supported themselves by logging and raising cattle and sheep, sometimes on a large scale. Transportation to and from the South Slough homesteads was almost entirely by boat and dependent on favorable tides. A small coal mine operated in the southern part of the South Slough watershed during the late 1880's, and the Chicamin mine operated from about 1915 to 1926 to extract fine gold and other minerals from the black sandy sediments. Small coal mines operated in the southern region of the South Slough watershed until the early 1900's.

During the prohibition period (early 1920's) Valino Island was the site of a speak-easy tavern or "blind pig", but no physical structures remain. Many of the early buildings and homesteads in the watershed were abandoned during the Depression and have collapsed or been razed. The sites of several older buildings, including an old schoolhouse and a shake mill, are known, but their vestiges are now marked only by small piles of decaying lumber. One of the last buildings of this period still standing in the South Slough watershed is the Fredrickson House (*ca.* 1924). By 1900 families who had taken up residence in South Slough had substantially altered the landscape to accommodate agricultural, transportation and logging needs. Salt marshes were separated from the tides with large earthen dikes and drained by ditches. Tide gates kept out saltwater but also slowed the drainage of freshwater. As a result, the former salt marshes became wet meadows and freshwater wetlands where cattle could graze. The dikes also served as roadways and supported raised bridges across small streams or marshy areas. In 1936 a large forest fire broke out east of Bandon (25 miles south) and burned significant portions of the South Slough watershed but stopped at the location of the Fredrickson House.

Most of the pastures created by diking and draining were abandoned in the 1930's (however cattle continued to graze on one parcel within the Reserve until the early 1990's). Cattle ranching continues to the present along the Winchester Creek tributary that drains into the South Slough estuary. Many tide gates began to fail in the

1960's and most were allowed to deteriorate. In a similar fashion, the earthen dikes gradually eroded and many were breached. As a result, the former pasture lands are in various stages of reversion from freshwater wetlands to diverse estuarine mudflats and emergent marsh habitat. Dikes and drainage channels remain evident, particularly in the upper reaches of the South Slough. Creeks in the shallower parts of the Slough were dredged during the early to mid 1900's for logging and other transportation needs. Some creeks and banks are deeply scarred by historic splash-damming (creation of dammed log pond followed by sudden release of a large volume of water to float logs downstream). Surplus dredge spoils were piled high in some locations and remain as small islands.

Contemporary logging and road building activities produced some of the most obvious and lasting changes in the uplands of the South Slough watershed. All of the forests within the watershed have been harvested at least once, and the majority of forest lands continue to be managed by public and private owners for commercial timber production. The upland forest landscape is marked by a spatial mosaic of clearcuts in various stages of recovery, compacted and eroding dirt roads, scarified log landing sites, and the remnants of trestle railroads. Sections of the estuary shoreline within Winchester Creek and Talbot Creek are lined with vertical pilings that supported docks and a small railroad, and other pilings were used to aid in the transport of floating log rafts. The most recent harvests of commercial timber inside the present administrative boundaries of the South Slough NERR were completed in 1976, and a small private inholding was logged in 1992.

1.4.3.d Reserve Protection Efforts and Environmental Stewardship

The lands and waters encompassed by the South Slough NERR are permanently protected by Oregon statute (O.R.S. 273.533) in order to: (a) maintain the natural integrity of the estuary, (b) protect the estuary from uses and activities both within and beyond its boundaries which may alter or affect the ecosystem and its natural dynamic processes; and (c) preserve the area for long-term scientific and educational uses. South Slough NERR Administrative Rules restrict potentially harmful activities including brush picking, overnight camping, the use of chemical fertilizers, herbicides, and pesticides, digging for historical artifacts, open fires, hunting for waterfowl and game (allowed only as permitted by Oregon Department of Fish and Wildlife regulations), grazing of cattle, motorized boating, commercial oyster cultivation, and the recreational collection of geological deposits and minerals. Clearcutting of timber within the boundaries of the South Slough NERR is prohibited.

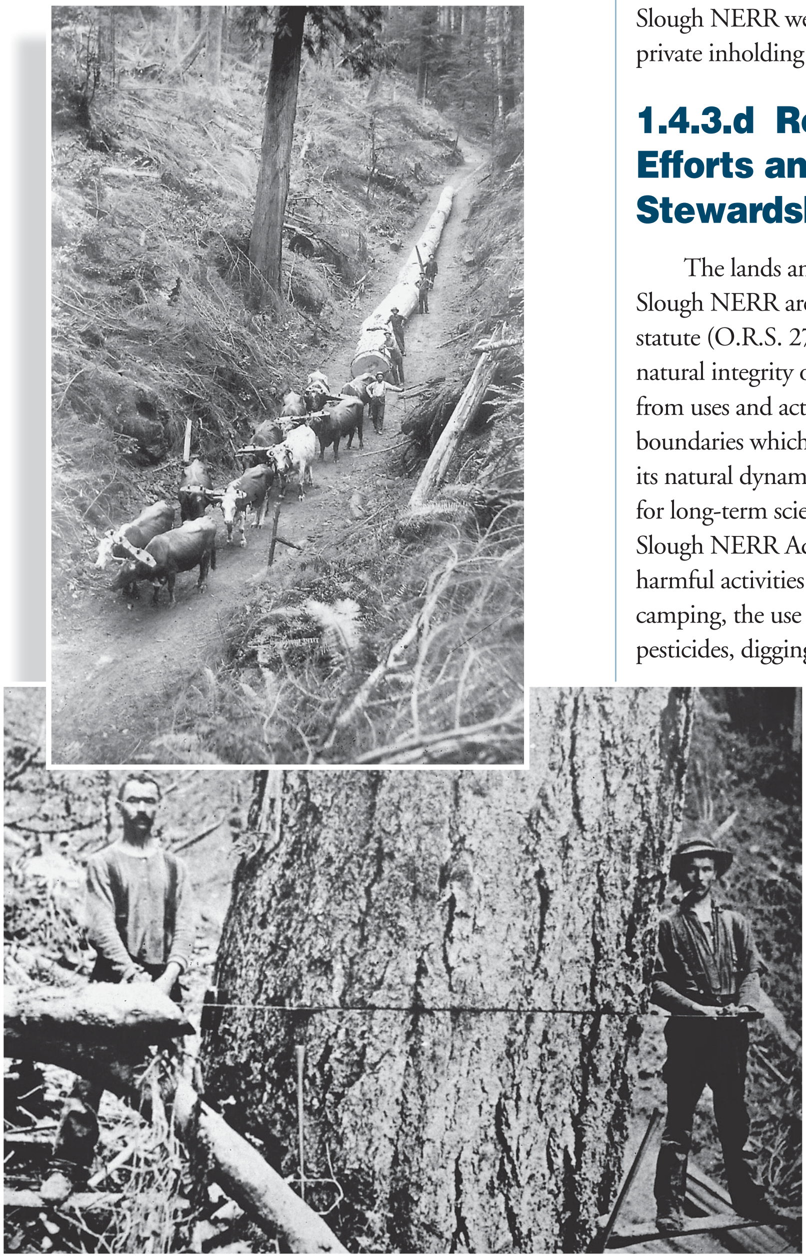


Figure 1.35. Early logging activity within the Coos and South Slough watersheds, *ca.* 1900 (from South Slough NERR archives).

Chapter 2

Geological Framework and Environmental Setting

2.1 Coastal Geology within the Charleston Quadrangle

The South Slough estuary and drainage basin of the surrounding watershed were formed by the interaction of several coastal geomorphic processes in the recent geologic past. These include slow coastal uplift and sudden subsidence driven by tectonic movement of offshore crustal plates, regional transgression and regression of the sea as a result of ice-age glacial advance and retreat, and fluvial erosion of a major riverine drainage system caused by differential coastal uplift.

2.1.1 Coastal Tectonic Setting

The history of the Coos estuary and South Slough watershed over the past few million years is a result of tectonic interactions between the Pacific, Gorda, Juan de Fuca, and North America Plates (Figure 2.1; Snavely *et al.,* 1977; Clarke *et al.,* 1985; Snavely, 1988; Briggs and Peterson, 1992; Nelson *et al.,* 1998; Yeats *et al.,* 1998). Rapid lateral displacement of the Pacific and North America Plates along the Queen Charlotte Fault (north) and San Andreas Fault (south) has occurred in an intermittent manner at an average rate of nearly 60 mm year^{-1} over the past 50 Ma. These large-scale crustal movements have been coupled with localized sea-floor spreading along the Gorda Ridge (20-50 mm year^{-1}) and Juan de Fuca Ridge (40-100 mm year^{-1}), slip of the Juan de Fuca plate along the Blanco fracture zone (a transform fault), and by subduction of the Juan de Fuca plate beneath the North American continent (Clague *et al.,* 1984; Clague, 1997; Komar, 1998).

Continual tectonic displacement of the Juan de Fuca Plate along the Blanco Fracture Zone builds up tremendous strain in the underlying rock layers and has contributed to long-term compression of sedimentary materials along the continental margin of the Oregon coast. Oblique convergence created by subduction of the Juan de Fuca plate beneath the North America plate has folded and warped the outer continental shelf margin (shelf and slope) into a succession of predominantly north-trending marine basins (Clarke *et al.,* 1985; Goldfinger *et al.,* 1992; Yeats *et al.,* 1998). These subduction events result in slow long-term uplift of coastal areas in Oregon. Strain that accumulates in the crustal plates as a result of plate interactions is released episodically during large earthquakes that occur both within and between the plates. The largest earthquakes occur along the subduction-zone boundary between the Juan de Fuca and North America plates (Figure 2.1), and they typically result in sudden coastal subsidence events of 0.5 to 2 m that almost offsets the accumulated long-term uplift (Nelson and Personius, 1990; Darienzo and Peterson, 1990; Clague, 1997).

2.1.2 Geologic History of the South Slough Watershed

South Slough is an elongated, north-south tidal basin located near the entrance of the Coos estuary (Figure 2.2). Sandstones, siltstones, and shales within the 7,930 ha (19,600 ac) South Slough watershed were deposited in deep marine seas and shallow coastal waters over the past 50 million years during the Tertiary and Quaternary periods (Eocene to Pleistocene geologic epocs; Figure 2.2). The sequence of sandstones, siltstones, and shales that make up the underlying Coaledo Formation bedrock were deposited during the cyclic transgression and regression of sea level. The basement layer of Coaledo Formation sediments is 1,200 to 1,800 m thick, and the existing surface layers are composed largely of an overburden of younger Empire Foundation mudstones, Bastendorf shale, and Quaternary marine terraces. The marine terraces that formed on these sedimentary rocks were cut over the past million years (McInelly and Kelsey, 1990; Madin *et al.,* 1995).

Sediments that form bedrock within the South Slough watershed and adjacent area (Charleston Quadrangle) were laid down in a complex sequence of transgressions and regressions that began in the

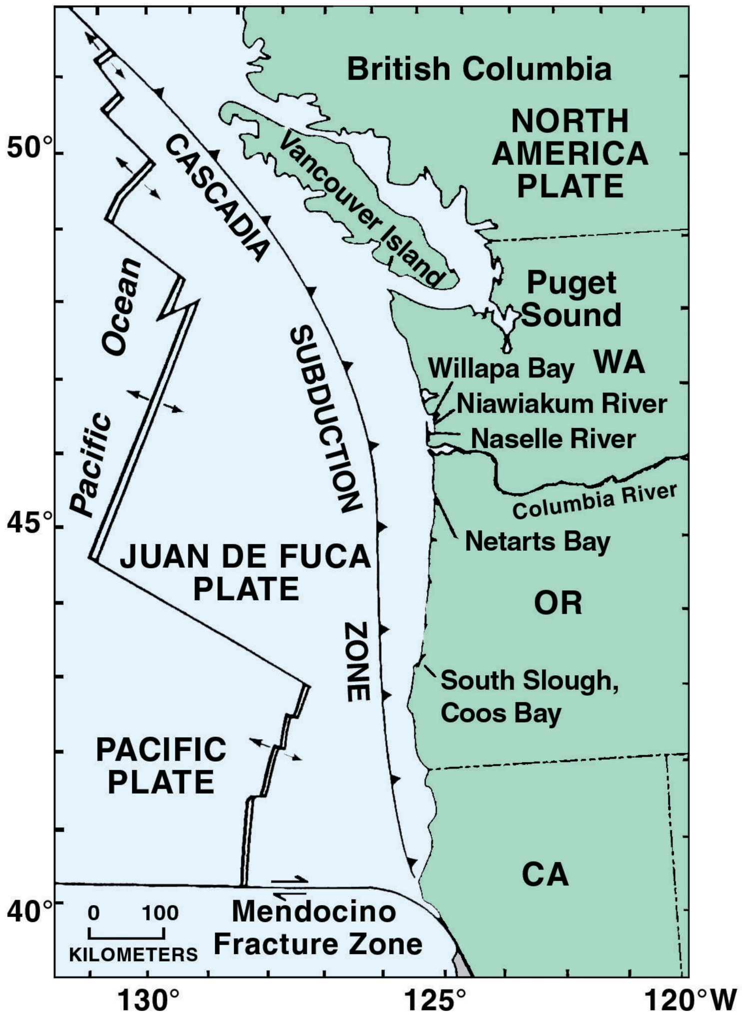


Figure 2.1. Tectonic movements of coastal plates along the Cascadia Subduction Zone. Continual tectonic displacement of the Juan de Fuca Plate along the Blanco Fracture Zone builds up tremendous strain in the underlying rock layers and has contributed to long-term compression along the continental margin of the Oregon coast. Tectonic pressure has resulted in development of the elongated South Slough syncline, and formation of the South Sough tidal basin.

middle Ecocene (*ca.* 40-48 Ma). The oldest sediments are micaeceous siltstone and mudstones of the Sacchi Beach beds (Madin *et al.,* 1995). These marine sediments were deposited in deep ocean water (180 to 600 m) and contain abundant microfossils (planktonic foraminifers, radiolarians and coccoliths) that are characteristic of a warm low-energy marine environment (Bukry and Snavely, 1988). The Sacchi Beach beds are exposed in the steep drainage basins of Five-mile and Three-mile creeks immediately west of the South Slough watershed (Figure 2.2). During the middle to late Eocene regression (38-45 Ma) sea level dropped and the ocean waters receded near Coos Bay. Consequently, the Sacchi Beach beds were buried beneath thick layers of deltaic mud, silt, and sand during progradation of the Coaledo Formation sedimentary complex. Coos Bay emerged as a distinct wave-dominated coastal embayment that was fed by rivers from the Klamath - Siskiyou Mountains and the Oregon Cascades (Ryberg, 1978; Clarke *et al.,* 1985).

The paleoenvironment of the regressive Coos deltaic coastal basin was characterized during deposition of the Lower Coaledo Formation (siltstone, mudstone, coal, and conglomerate) by a wet climate with extensive swamps and marshes. Lower Coaledo Formation beds contain abundant microfossils, bivalves, gastropods, evidence of bioturbation, and large amounts of terrigenous plant debris (see Figure 2.5; Orr and Orr, 1999). In contrast, finer-grained Middle Coaledo beds (siltstone, mudstone, and sandstone) were deposited in deeper coastal waters during a transgression, while the Upper Coaledo beds (siltstone, mudstone, coal, and conglomerate) were deposited in shallow water during a subsequent regression. The Coaledo Formation beds are exposed primarily along the hillsides and valleys on the east side of the South Slough watershed, but they also appear in Cox Canyon and along the western tributaries that drain into Winchester Creek (Figure 2.2, Figure 2.14).

Finely-laminated beds that make up the overlying Bastendorff Formation shale were deposited in a bathyal environment during the late Eocene (*ca.* 40-42 Ma) in another transgression of deep ocean water. These shale beds also contain abundant foraminiferal microfossils and invertebrates. Bastendorf Formation beds are exposed along the steep hillsides of Dalton Creek and Theodore John Creek (Figure 2.2, Figure 2.14). Finally, the Tunnel Point Sandstone (containing siltstone, minor conglomerate, and mollusc fossils) was deposited in shallow water at the end of the Eocene (*ca.* 40 Ma). A thin section of Tunnel Point Sandstone is exposed on the northwestern flank of the South Slough watershed. The orderly sequence of these sedimentary layers (Coaledo, Bastendorf, and Tunnel Point Formations) indicates that they were deposited in a tectonically stable environment (Madin *et al.,* 1995).

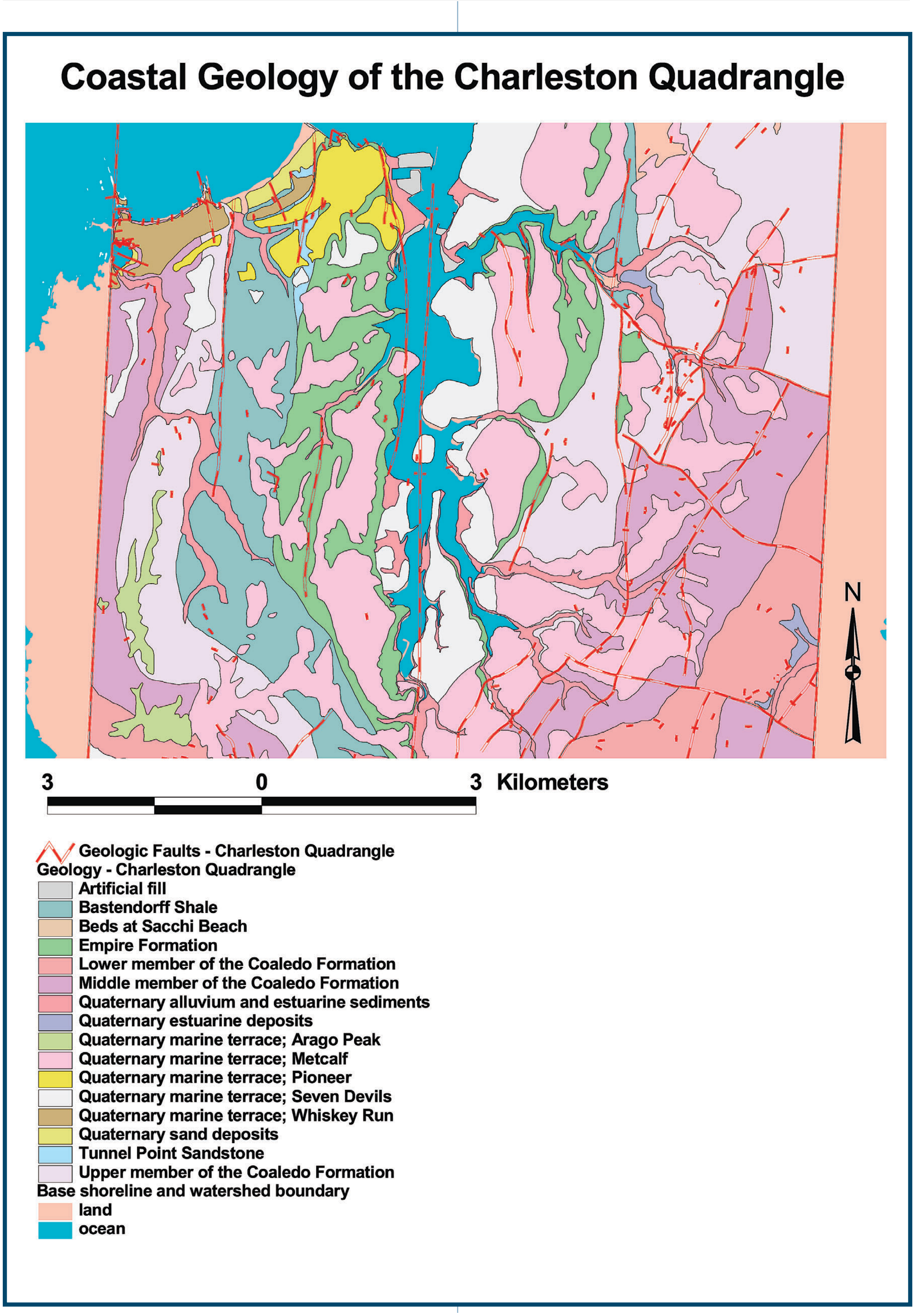


Figure 2.2. Coastal geology of the Charleston quadrangle. The South Slough syncline forms the elongated trough of the estuarine tidal basin.

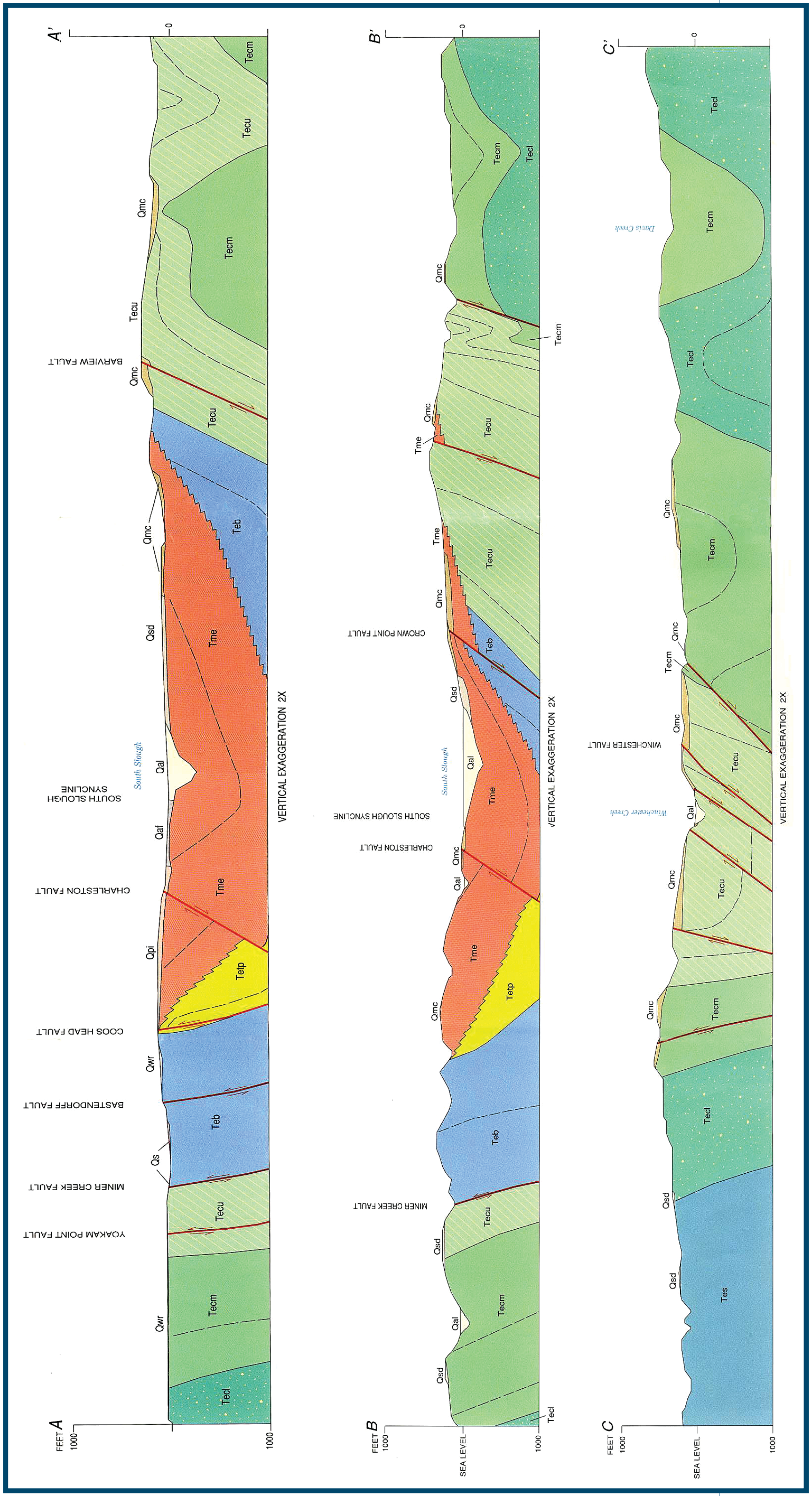


Figure 2.3. Geologic cross-sections through the South Slough syncline and estuarine tidal basin. A, Northern region at estuary mouth; B, middle region at Younker Point; C, southern region at head of tide. Major unconformities are indicated by wavy lines.

2.1.2.a Origins of the South Slough Syncline

An abrupt angular unconformity representing nearly 30 million years separates the older Eocene bedrock from the more recent Miocene to Pliocene and Quaternary deposits within the South Slough watershed. Absence of sediments dating from the Oligocene and early Miocene (8 to 36 Ma) indicates a significant period of non-deposition, probably related to the onset of tectonic plate deformation along the Cascadia subduction zone (Darienzo and Peterson, 1990; Madin *et al.,* 1995). Long-term deformation of coastal deposits by coseismic shifting of the North America and Juan de Fuca plates contributed to east-west compression of the sedimentary rocks and to formation of the South Slough syncline.

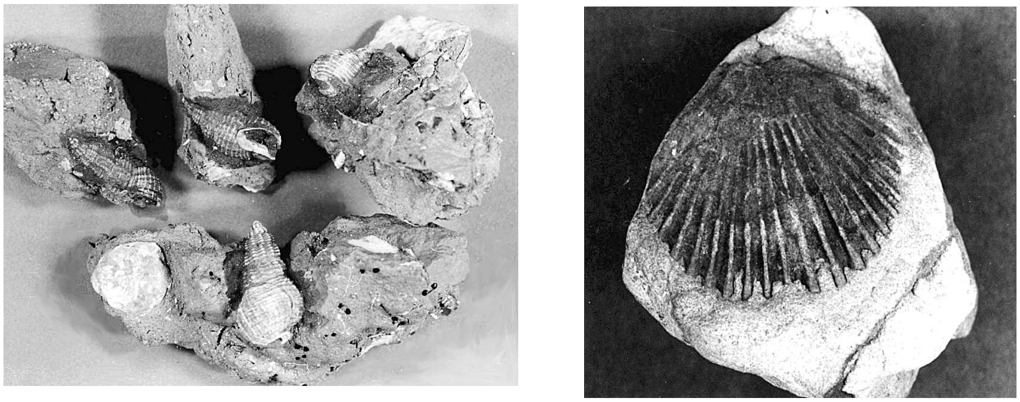
The South Slough syncline is the principal geologic feature of the Charleston quadrangle, and it occurs as an elongated north-trending fold in the Tertiary bedrock (Figure 2.3). Continued east-west compression over tens of millions of years along the axis of the South Slough syncline has produced many other north-trending folds, anticlines, and reverse faults in the Cascadia fold and thrust belt (Goldfinger *et al.,* 1992; Yeats *et al.,* 1998). South Slough marks the point where the thrust belt comes onshore; north of Coos Bay most compressional structures occur offshore on the continental shelf and slope (Figure 2.1).

The South Slough syncline forms a markedly asymmetric trough beneath the elongated and narrow South Slough estuary. The western side of the syncline consists of steeply-dipping Miocene and Pliocene sandstone and Eocene shale (Figure 2.3). The axis of the South Slough syncline is parallel on its western side with three major north-trending reverse faults (the Charleston Fault, the Hayward Creek Fault, and the Miner Creek Fault). In contrast, on the eastern side of the syncline, gently sloping Quaternary marine terraces are cut on the underlying bedrock and offset by several minor cross faults (*i.e.* Barview, Joe Ney, Crown Point, Day, and Winchester faults; McInelly and Kelsey, 1990; Madin *et al.*, 1995).

2.1.2.b Miocene and Pliocene Deposits

Sedimentary deposition resumed in the area of the Charleston quadrangle during the middle to late Miocene (10 - 6 Ma). Sediments from the Miocene Tarheel Formation (with sparse bivalve fossils) were probably deposited in warm temperate seas on the upper continental shelf at depths of about 60 m. These sediments are exposed near the mouth of South Slough where absence of fossil shells from brackish or freshwater species indicates that the estuary did not exist at that time (Armentrout, 1967; Orr and Orr, 1999). The poorly bedded concretionary sandstone of the Empire Formation was deposited in a high-energy shallow temperate coastal basin during the late Miocene and Pliocene. The Empire Formation sandstone contains many pebbles of basalt, quartzite, and chert along with abundant fossil bivalues, gastropods, and occasional marine mammals (Figure 2.4; Armentrout *et al.*, 1983). Empire Formation sandstones are exposed at several locations along the steep western shores of the South Slough estuary, and they form prominent cliffs at Collver Point and Coos Head near the entrance to the Coos estuary.

Another angular unconformity of about 4 million years separates the Tertiary Tarheel and Empire Formation sandstones from more recent Pleistocene marine terraces and Holocene estuarine deposits that are distributed irregularly over much of the South Slough watershed. The Pilocene-Pleistocene unconformity is widespread on the



A. *Nassarius:* Coaledo Formation

B. *Pecten:* Empire Formation

C. Assemblage of fossil molluscs including *Ostrea* and *Nassarius* within matrix of soft sandy mud: Coaledo Formation

D. *Clinocardium* / *Venerupsis:* Coaledo Formation

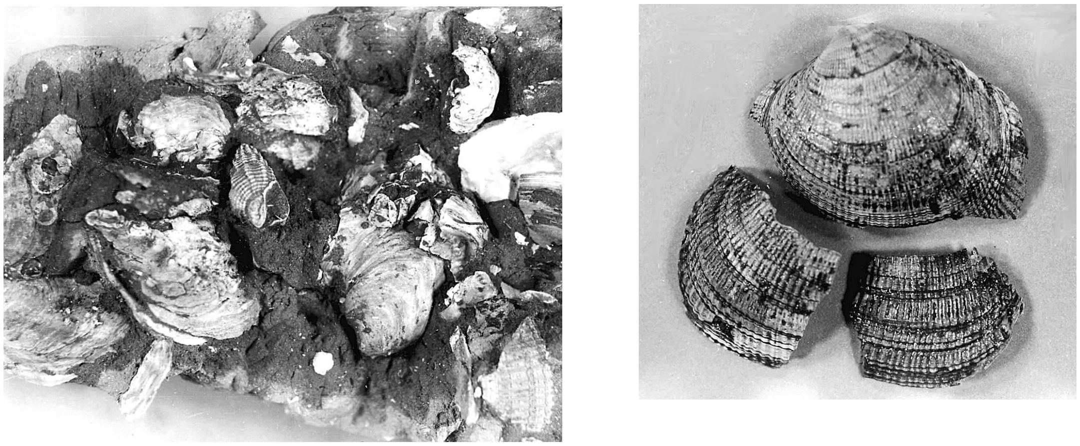


Figure 2.4. Fossil invertebrates recovered from Empire and Coaledo Formation sediments within the Sough Slough. Photos and tentative identifications by Nyborg, 1993.

central and northern Oregon shelf (Clarke *et al.*, 1985). In the Charleston quadrangle, the unconformity results from erosion and nondeposition during periods of glacial advance and low sea level coupled with continued uplift and tightening of the South Slough syncline (McInelly and Kelsey, 1990; Madin *et al.*, 1995; Orr and Orr, 1999).

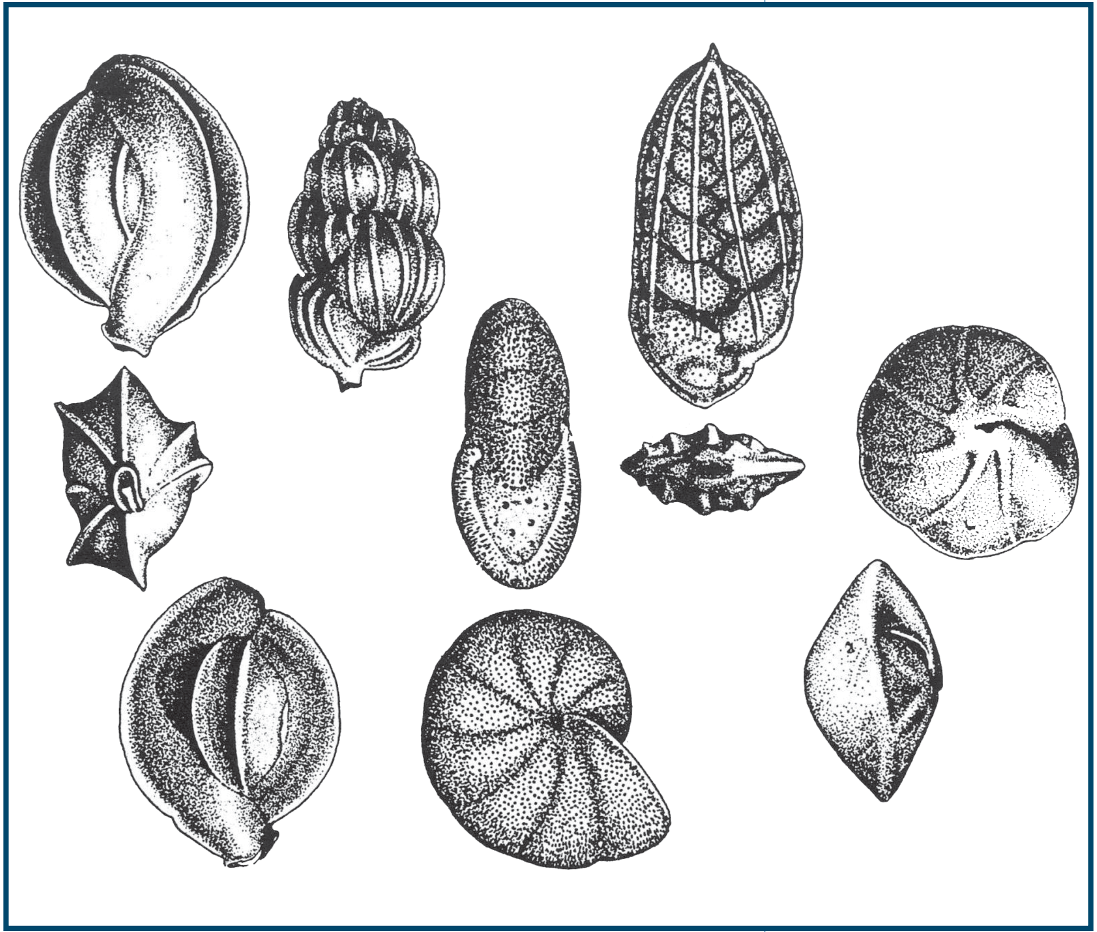


Figure 2.5. Bottom-dwelling foraminifera representiative of those founds in the Coaledo and Bastendorff formations (from Orr and Orr, 1999).

2.1.3 Quaternary Geologic History

Two primary geologic processes dominated geomorphic evolution of the South Slough tidal basin during the Quaternary period (the past 2-3 million years). First, continued east-west compression of the North America plate produced long-term coastal uplift and further tightened and faulted the South Slough syncline and other folds throughout the southern Oregon coastal region (McInelly and Kelsey, 1990; Nelson, 1995; Yeats et al., 1998). Folding and faulting that accompanied coastal uplift caused different areas of the coast to rise at different rates (Kelsey *et al.*, 2002). In particular, uplift of north- or northwest-trending anticlines and faults during the past 1-2 million years has significantly altered the topography of the Coquille - Coos drainage basin. The historic drainage network of river valleys and streams developed in response to differential movement on anticlines, synclines, and faults. Basin geomorphology suggests that the Coquille River once drained into the Pacific Ocean through Isthmus Slough, the Winchester Creek valley, and South Slough (Baldwin, 1945; Nyborg, 1993; Nelson, 1995). Furthermore, several outcrops of Pleistocene alluvial floodplain materials (that include fine-grained sand, silt, clay, and gravel along with characteristic bivalve and gastropod fossil assemblages like those found at the mouth of the Coquille River) occur along the shoreline of the South Slough estuary (Nyborg, 1993). Subsequent folding, faulting, and uplift of anticlines (ridge areas) in the South Slough watershed during the late Tertiary - early Quaternary probably caused the mouth of the Coquille River to shift southward toward its present location at Bandon.

Sea-level change during the repeated marine transgressions and regressions of the Quaternary period is the second important process to shape the geomorphology of the South Slough tidal basin. Significant fluctuations in climate led to cyclic advance and retreat of continental glaciers and rise and fall of sea level (up to 120 m over tens of thousands of years). Successive changes in sea level caused the shoreline to migrate back and forth over tens of kilometers and formed a series of step-like marine terraces in the Charleston quadrangle (McInelly and Kelsey, 1990). The marine terraces are composed of weakly-consolidated medium-grained sandstone and pebble conglomerate that was deposited in a littoral marine environment. Quaternary marine terraces within the South Slough watershed include the: (a) Metcalf terrace (200,000 years old), (b) Seven Devils terrace (125,000 years old), and (c) Pioneer terrace (105,000 years old). Immediately south of the South Slough watershed, the Whiskey Run terrace (83,000 years old) provides evidence of the most recent episode of Pleistocene marine transgression. Over the past 18,000 years the climate of the Pacific northwest region warmed gradually, continental glaciers retreated, and sea level rose to flood low coastal valleys. During this period, alluvial and estuarine sediment eroded from the marine terraces gradually filled the South Slough tidal basin. The low-energy tideflats and channel sediments that exist today are a mixture of sand, silt, and clay.

2.1.3.a Late Holocene History of Sea-Level Rise and Great Earthquakes

Gradual rise of marine sea-level is the principal process that influenced the South Slough during the late Holocene (past 4,000 years). Radiocarbon ages of microfossils indicate that the long-term rate of sea-level rise has been about 1.4 m per 1,000 years over the past 4,000 years in South Slough (Nelson *et al.,* 1996b; Nelson *et al.,* 1998) and in other parts of Coos Bay (Briggs, 1994). Beginning at an elevation of about 4-5 m below present sea level (about 4,000-5,000 years ago), sea level has risen at a relatively constant long-term rate to within 0.5 m of the present elevation of mean sea level (about 500-1,000 years ago). Uncertainty in these estimates of radiocarbon ages (± 200-400 years) and sea-level elevations (± 0.5 to 1.0 m) adds difficulty to the precise interpretation of late Holocene history (Nelson *et al*., 1996a). Prevalence of peat layers in the upper 1.0-1.5 m of sediment cores taken from brackish marshes in many parts of the Coos estuary suggests a reduction in the rate of sea-level rise or an increase in the rate of sedimentation over the past 1,000 to 1,500 years. In South Slough, the infilling of the estuary with tidal and fluvial sediment may have kept pace with sea-level rise. The extensive tideflats that exist throughout the estuary probably formed recently during the past 1,000 to 2,000 years.

Geologic investigations conducted over the past 15 years have uncovered compelling stratigraphic evidence that much of the coast of central western North America has experienced repeated great earthquakes (magnitude greater than 8) and accompanying tsunamis over the past 6,000 years (Hyndman, 1995; Atwater *et al.,* 1995; Darienzo and Peterson, 1995; Nelson *et al.,* 1996a; Atwater and Hemphill-Haley, 1997; Clague, 1997; Kelsey *et al.,* 2002). These studies indicate that great earthquakes of at least magnitude 8 (and their accompanying tsunami) have occurred on average every 500-600 years. The time interval between successive earthquakes, however, is considerable and varies from decades to almost a millennia. The most recent great earthquake and tsunami to impact the Oregon coastal region and South Slough occurred on 26 January AD 1700 (magnitude 9 at about 9 pm; Satake *et al.,* 1996). Like other great subduction-zone earthquakes, the recent earthquake of 1700 was caused by a sudden slip of the Juan de Fuca plate beneath the North America plate along the 1,000 km long Cascadia subduction-zone. Based on analogies with the largest subduction zone earthquakes of this century in Chile (1960, magnitude 9.5; Atwater *et al.,* 1999) and Alaska (1964, magnitude 9.2), elastic thinning of the North America plate (or shallower faulting within it) resulted in 0.5-1.0 m of permanent subsidence along significant parts of the central Oregon coast (Atwater, 1987). Since the average recurrence interval for major earthquakes along the Oregon coast is about 400 years, and the most recent large-scale subsidence event occurred about 300 years ago, the probability of a future earthquake and coastal subsidence event is conservatively estimated at 10-20% within the next 50 years (or 20-40% within the next 100 years).

2.1.4 Formation of Buried Peat Layers

The presence of abruptly buried peaty soils (formed within coastal marshes and swamps) revealed in exposed outcrops and sediment cores beneath intertidal lowlands provides a stratigraphic record of the consequences of rapid coastal subsidence. The sudden rise in effective sea level produced by subsidence of the coastal land mass quickly buried the soils with intertidal mud. In cases where there was a nearby source of tidal sand, large tsunamis that accompanied the earthquakes spread sheets of sand over the marshes and swamps higher and farther inland than even the largest storm surges.

Sudden submergence of the South Slough tidal basin resulted in a rapid influx of high-energy sands followed by the slower accumulation of finer estuarine sediments. The subduction zone earthquakes also generated uplift in the surrounding coastal lands (Nelson and Personius, 1990). As a consequence of uplift in the adjacent hills, the secondary drainage basins increased in slope and fluvial sediments rapidly filled the South Slough tidal basin. During interseismic periods (between tectonic events), the coastal hillslopes and lowlands were stabilized and vegetative communities developed and decomposed *in situ* to form a growing layer of peat that maintained its elevation in response to changes in local sea level. It is likely that topographic elevation of the South Slough (Winchester Creek) tidal basin kept relatively constant pace with incremental changes in local sea level throughout the Holocene period of recent geologic history (10,000 years ago to the present).

Stratigraphic investigations of lithology and analysis of the composition and age of microfossils buried within estuarine soils and salt marsh peat layers indicate that the South Slough tidal basin has undergone catastrophic subsidence of 0.5 to 1.0 m at least three times over the past 4,000 years (Figure 2.6; Nelson, 1995; Nelson *et al.*, 1996b; Nelson *et al.*, 1998). A distinct layer of clean sand overlies the youngest subsided tidal marsh soil (organic peat layer) at a depth of about 0.5 m below the present marsh surface at many locations in the northern region of South Slough (Hayward Creek, Crown Point, Day Creek, Joe Ney Slough; Peterson and Darienzo, 1989; Nelson *et al.*, 1998). The sand layer was probably deposited by the tsunami and great earthquake of 1700 (Satake *et al.*, 1996). Fossil evidence collected from locations in the southern region of South Slough indicates that the tidal basin was impacted previously by older earthquakes and tsunamis (*ca.* 1,500-1,800 years ago and 2,400-2,700 years ago; Nelson *et al.*, 1998).

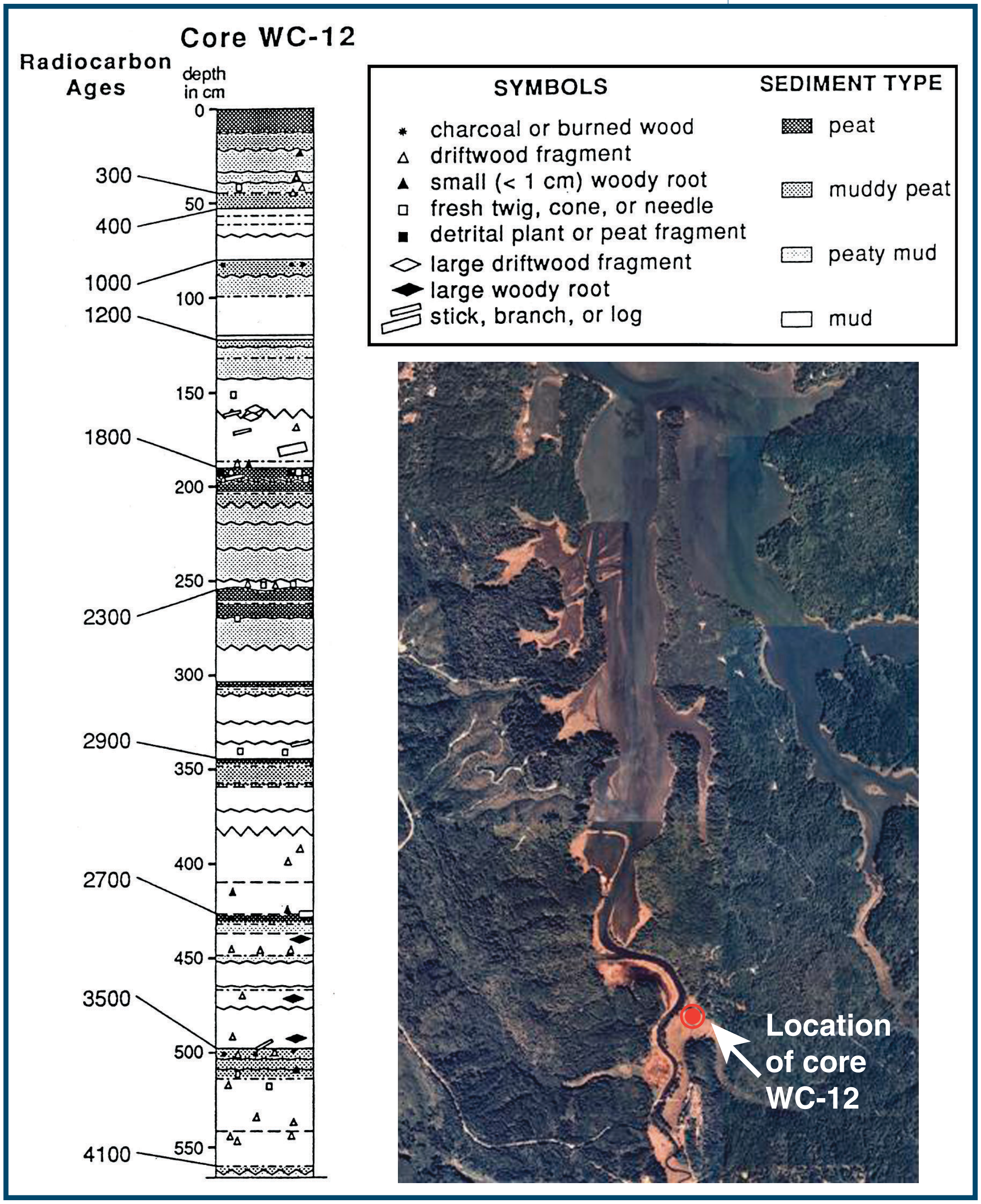


Figure 2.6. Representative stratigraphic core from South Slough salt marsh. Core ◉ contains evidence of repeated episodic subsidence, and inundation of the tidal basin by a tsunami 300 years ago (adapted from Nelson, 1995, in Caldera, 1995).

Although Nelson *et al.,* (1998) acknowledged the possibility that all but one of the ten buried tidal marsh peat layers they examined beneath the marshes of South Slough might record great earthquakes and tsunamis, they conservatively interpreted the stratigraphic cores to confirm only three. For example, they along with other researchers (Peterson and Darienzo, 1989; McInelly and Kelsey, 1990) suggest that some suddenly-subsided peat soils might record local displacement on shallow faults or smaller-scale folding of the South Slough syncline either independent or synchronous with the great subduction-zone earthquakes. Additional studies conducted along the southern Oregon coast (Kelsey *et al.,* 2002) provide further evidence of repeated subsidence and suggest that South Slough has been inundated by tsunamis at least 8 times in the past 4,000 years.

At least some subsidence events recorded in stratigraphic cores and rapid burial of peaty soils in the South Slough result from coseismic displacement of sediments at the local level (Nelson 1987; Peterson and Darienzo 1989; Peterson 1989; McInelly and Kelsey 1990). For example, McInelly and Kelsey (1990) mapped and dated Pleistocene marine terraces and their underlying strata in the greater Coos Bay region and demonstrated that the South Slough syncline is currently subject to active deformation. Characteristics of the regional deformation, however, are more complex than previously assumed (Adams, 1984). McInelly and Kelsey (1990) dated historic tree stumps in the intertidal zone adjacent to flexure-slip faults within the South Slough syncline, and suggest they were caused by Holocene displacement events. The abruptly buried peat-marsh surfaces in the South Slough tidal basin probably result from coseismic displacements due to localized folding or faulting of the South Slough syncline. The elevational displacements they observed along the South Slough syncline were small (about 0.5 m) and could not be directly correlated with other buried marsh surfaces found elsewhere in the Coos Bay area.

2.1.5 Geomorphology of the South Slough Tidal Inlet

The South Slough tidal inlet is a north-south trending arm of the Coos estuary (Figure 2.7). The entire drowned river-mouth tidal basin is about 9 km in total length, about 600 m in average width, and has a total wet surface area of about 783 ha and an estimated tidal prism of 9.34 millon m^3 (Harris *et al.,* 1979). Northern sections of the South Slough estuary are directly influenced by marine waters from the lower region of Coos Bay and Pacific Ocean waters from the nearshore region immediately outside the jetties. The South Slough estuarine tidal basin contains three primary sub-systems: (a) Joe Ney Slough; (b) Winchester Arm; and (c) Sengstacken Arm. These three estuarine sub-systems drain into the common South Slough tidal channel. The Winchester Arm is the largest and most prominent of the sub-systems, and the elongated Winchester Creek tidal channel fills the downwarp of the South Slough syncline. The syncline is faulted and capped by uplifted Pleistocene marine terraces, and the tidal basin contains estuarine sediments and alluvium deposited over the last 7,000 years (middle and late Holocene). Geomorphology of the South Slough tidal inlet is strongly dependent on the location, size, and orientation of the South Slough syncline, particularly with regard to its seaward connection with the greater Coos estuary. The South Slough estuary encompasses four distinct hydrogeomorphic regions based on the extent of marine influence and location along the saltwater (SW) to freshwater (FW) estuarine gradient.

2.1.5.a Nearshore Area of Marine Influence (Marine–Estuarine Interface)

Marine waters from the nearshore Pacific Ocean and lower region of Coos Bay directly enter the northern region of the South Slough (Figure 2.7). This marine-estuarine interface zone is located immediately outside the mouth of the South Slough estuary and is characterized by euhaline waters with an average salinity range of 33 to 28 psu (practical salinity units). During seasons when the volume of freshwater discharge is high from the Coos and Millicoma rivers, the marine-estuarine interface zone extends as a visible plume beyond the Coos Bay jetties and into the nearshore area south to Gregory Point and northward outside the surf zone of North Spit. In contrast, during dry seasons the interface zone is relatively small and confined to the immediate region of mixing between marine and estuarine waters with the daily ebb and flood of the tides.

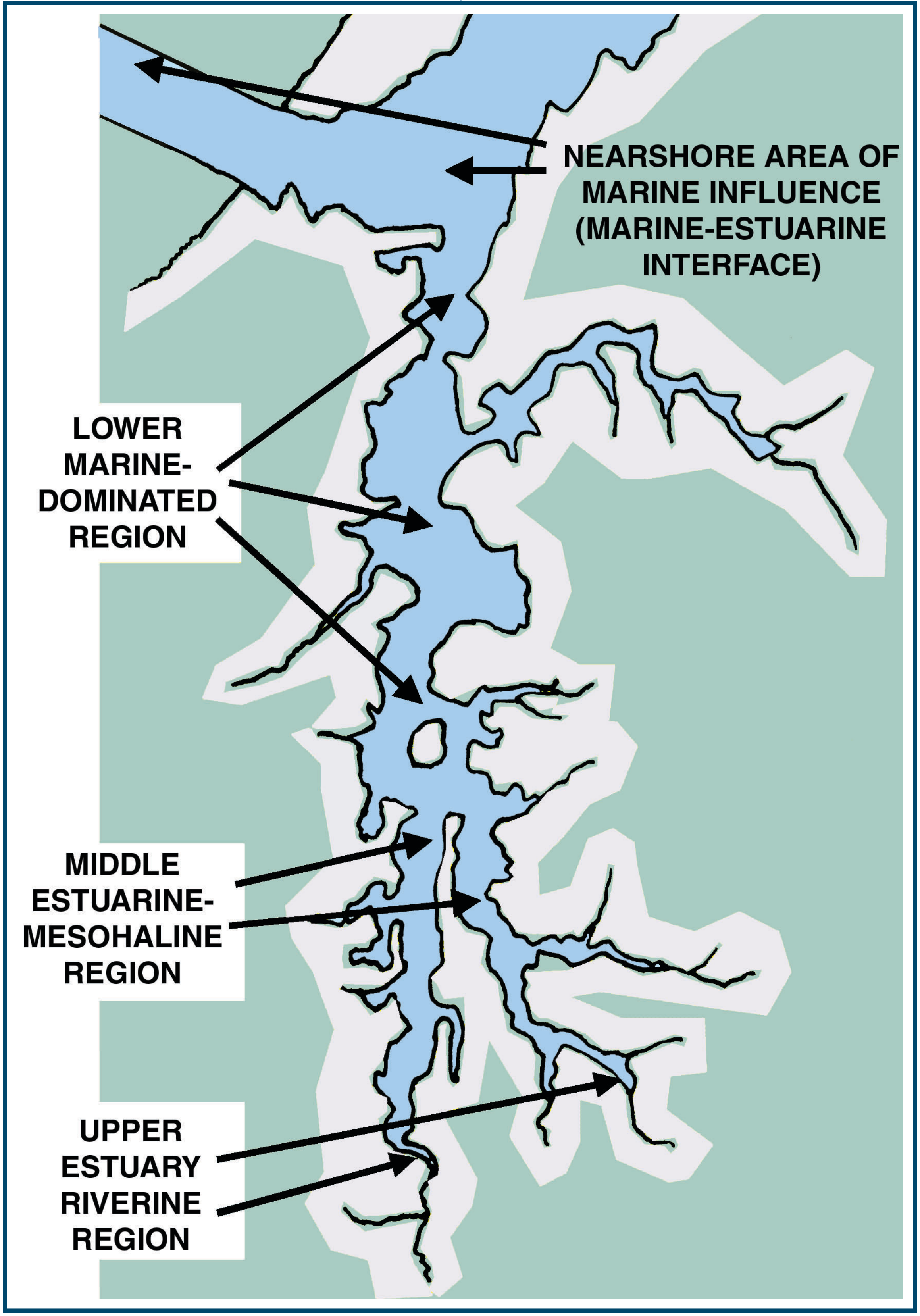


Figure 2.7. Major hydrogeomorphic regions of the South Slough estuary.

2.1.5.b Marine-Dominated Region and Joe Ney Slough

The marine-dominated region extends from the mouth of the South Slough tidal inlet (Fossil Point / Charleston) southward to Long Island Point and the convergence of the Winchester and Sengstacken arms (Figure 2.7). This large (*ca.* 350 ha) and heterogeneous area has a shoreline perimeter of about 25 km and a maximum depth of –5.5 m below NGVD near Collver Point. The marine-dominated region includes the deep waters of the Charleston Channel, several broad open tideflats, extensive eelgrass beds, and salt marshes. Substrata in this region include bedrock headlands (Collver Point), exposed and eroding sand cliffs (Younker Point, Crown Point, Valino Island, Ferrei Head, Long Island Point), and cobble, sand, and mud. The marine-dominated region receives freshwater input directly from rainfall and via three primary creeks that drain adjacent watershed sub-basins (Joe Ney Creek 1,340 ha; Hayward Creek 320 ha; Day Creek 417 ha). Additional freshwater enters this region indirectly (after mixing) during ebb tides from the Winchester and Sengstacken arms of the estuary. The marine-dominated region has a tidal amplitude of 2.7 m, and mean monthly temperatures range from 8-15 °C (Valino Island SWMP station; see Figure 2.22). The tidal waters are typically well-mixed throughout the year and range in salinity from a maximum of 33 psu to a minimum of 5 psu, although the monthly mean salinities fluctuate seasonally from 20 to 31 psu.

2.1.5.c Middle Estuarine-Mesohaline Region

The middle estuarine-mesohaline region of the South Slough extends along the lengths of the Winchester and Sengstacken arms from the tip of the Long Island Peninsula southward to Danger Point (Winchester) and to the Talbot Creek delta (Sengstacken; Figure 2.7). This region of the South Slough estuary encompasses a moderate spatial scale (225 ha) with a shoreline perimeter of about 17 km and a maximum depth of –3.5 m below NGVD (within the Winchester Creek tidal channel along the Long Island Peninsula). The estuarine-mixing region has a tidal amplitude of about 2.2 m (Gilman, 1993). Tidal waters in this region are typically well-mixed throughout the year with an average salinity range of 28 to 15 psu.

2.1.5.d Upper Estuary-Riverine Region

The upper estuary-riverine region of the South Slough extends to the head of tide along Winchester Creek and its tributaries (Cox Canyon, Wasson Creek, Anderson Creek) on the western side of the estuary, and along Talbot Creek and John B. Creek on the east side (Figure 2.7). This region of the South Slough estuary is also moderate in spatial scale (combined total 205 ha) and heterogeneous with narrow tidal channels and expansive open salt and freshwater marshes. The tidal channels are characterized by strong seasonal changes in discharge of freshwater, and the shallow channels have a maximum depth of -2.2 m NGVD. The riverine region of the Winchester arm has a tidal amplitude of 2.0 m (Winchester Creek SWMP station). Monthly mean salinities range from 4 to 20 psu, and mean temperatures range from 8 to 18 °C (see Figure 2.23). Similarly, the riverine region of the Sengstacken arm has a tidal amplitude of 2.1 m (Talbot Creek SWMP station), monthly mean salinities range from 3 to 20 psu, and mean temperatures range from 7 to 18 °C (see Figure 2.24). Tidal waters in the riverine channels are typically well-mixed in summer when the salinity ranges from 5 to 30 psu, and they are well-flushed and partially stratified during the rainy season when salinities range from 0 to 21 psu.

The Winchester Creek sub-basin is the largest drainage system in the South Slough estuary. The riverine region of Winchester Creek and its tributaries provide an avenue for freshwater, sediments and organic debris to move from the uplands into the middle and marine-dominated regions of South Slough. The Winchester Creek tidal channel varies in width from 5 to 7 m and has an overall sinuosity coefficient of 1.6:1 (curve length:linear length). Two meanders in the Winchester Creek channel have developed around large rootwads. Lateral scour pools formed by sediment deposition and erosion around the rootwads are examples of geomorphic features that were more prevalent prior to Euro-American settlement. It is likely that early settlers removed rootwads that were impediments to navigation and transport of floating logs. Remnant earth levees and dikes are present along the shoreline from the northern end of the Winchester Creek tidal basin (Lattin Dike) throughout the old pastures, agricultural plots, and experimental marsh restoration sites encompassed by the Winchester Tidelands Restoration Project area (Kunz, Tom's, Dalton, Tracy, and Fredrickson marshes).

2.1.6 Recent Alterations to the Geomorphology of the Tidal Channels

Historical records and anecdotal information indicate that the tidal channels and shoreline of the South Slough estuary have undergone considerable alteration over the past century. U.S. Coast and Geodetic Survey maps (1865, 1879) provide an early illustration of the historic shoreline and extent of tidal wetlands within the South Slough. The first Euro-Americans settled in Charleston (South Slough), Empire City, and Coos Bay (Marshfield) in the 1850's. Anthropogenic activities including prospecting for placer deposits, coal mining, logging, subsistence farming, dredging, and the construction of shoreline roadways significantly altered the geomorphology of tidal channels and adjacent coastal landforms (Douthit, 1986). For example, the first lumber mill was constructed on the banks of the South Slough by G. Wasson and T. Winchester in the early 1860's, and a diversion dam and water-wheel created a large pond in Winchester Creek (Caldera, 1995). Although the lumber mill was operational for only a short period, the dam probably raised the base level of Winchester Creek and its tributaries. Retention of slow-moving water by the Winchester Creek dam contributed to accretion of fine sediments in the bottomlands and lower ends of the tributaries. Coupled with disturbance to soils associated with road building and log transport, the net effect was likely a rapid increase in sedimentation and subsequent growth of emergent marsh vegetation in low-lying areas influenced by the dam.

The early homesteaders and subsistence farmers within the South Slough watershed also built an extensive series of dikes, excavated ditches, and dug new canals in the bottomlands of the tributary canyons in order to protect livestock areas from saline tidal waters and to facilitate drainage of the tidal marshes and adjacent freshwater wetlands. These early agricultural activities eliminated tidal circulation from salt marshes at several locations in the estuary (*i.e.,* Winchester Tidelands, Lattin Dike, Rhodes Dike, Sloughside Dike, Ferrei Head marsh, Wick Creek, John B. Creek, Elliott Creek, Day Creek, Hayward Creek, Joe Ney Slough). The earthen dikes also diverted streamflow from the natural network of dendritic tidal creeks into a series of linear ditches and tidegates that emptied into the primary tidal channel. Dredging activities were also carried out along the length of Winchester Creek in order to facilitate transport of floating log rafts to industrial port facilities in Coos Bay. A series of elongated dredge spoil islands were deposited in the middle region of the South Slough estuary that remain today as prominent features of the estuarine tidal landscape.

Taken together, the historic and recent alterations to the estuarine tidal basin suggest that the South Slough estuary (like the Coos estuary as a whole) is currently in a state of geomorphic disequilibrium. The dynamic status of the shoreline and tidal channel is partially attributable to natural processes but also related to shoreline urbanization and significant enlargement of the Coos Bay navigation channel over the last century (ACOE, 1993). Tidal circulation patterns have changed, the tidal prism within the Coos estuary and South Slough has increased, and several earthen dikes have breached to allow re-flooding of former tidelands. These passive restoration events serve to further enlarge the tidal prism within the South Slough and regain the morphodynamic equilibrium that was disrupted by dike construction and deepening of the navigation channel (Beaulieu and Hughes, 1975; Case, 1983; ACOE, 1993; Madin *et al.,* 1995).

2.2 Regional and Local Climate Conditions

Meteorological data compiled from the North Bend Airport Weather Station (located about 10 km northeast of Charleston; see Figure 1.20) illustrate seasonal and interannual trends in temperature, precipitation, and winds. Local monthly rainfall records date from 1903 and provide nearly a century of uninterrupted data. Although these measurements are taken a substantial distance north of the South Slough, they are characteristic of the northern region of South Slough estuary.

2.2.1 Seasonal Temperature, Precipitation, and Wind Patterns

The South Slough estuary experiences two distinct climatic seasons over a typical year. The warm (mean 13-15 °C, max 21-28 °C / min 5-10 °C) and relatively dry season extends from May through September-October, and the cooler (mean 7-10 °C, max 15-20 °C / min –2-2 °C) and cloudy wet season extends from November through March. April is typically an intermediate period marked by the spring transition reversal of coastal winds, cessation of rainfall, and rapid warming of air temperatures. Long-term average monthly temperatures for the shoreline of the Coos estuary range from a low of 7 °C to a high of 16 °C (see Figure 1.8). Precipitation occurs primarily in pulses of 3-5 day rainfall events between October and May, with a long-term average monthly rainfall of nearly 30 cm in December and January and less than 2 cm in July. Total annual rainfall ranges from 147-158 cm yr^{-1} and the watershed annually receives about 2-6 cm of snow.

2.2.2 Pulsed Storm Events

During the wet winter season (November-March) the Coos estuary and South Slough are battered by a series of maritime storms generated during cyclonic (counter-clockwise) circulation of the moist oceanic air masses around the Aleutian low pressure zone (Schultz, 1990). Storms driven by these south-westerly winds typically move inland from the ocean every 10-18 days, and each storm lasts about 3-6 days (Figure 2.8). These storms can sometimes deliver 7-10 cm of rainfall in a 24 hr period. Wind velocities can reach hurricane speeds (greater than 120 km hr^{-1}) and generate ocean waves up to 7 m during intense storms. Wind speeds during more typical storm events are on the order of 12.6 to 18.0 km hr^{-1}, and ambient winds average about 3-4 km hr^{-1} (Juza, 1995). Daily records of rainfall, local winds, and ambient air temperatures indicate that 8-14 storm events typically occur throughout the wet season. Winds are less intense between winter storms and generally blow from the north and northwest.

During spring and summer months the Aleutian low pressure zone dissipates, the north Pacific high pressure zone develops, and winds reverse to blow predominantly anti-cyclonic (clockwise) from the north and northwest (see Figure 1.7). Wind velocities are typically low in the morning, increase throughout the day, and decrease in the evening. This secondary diel pattern is caused by interaction of the cool north Pacific high pressure zone (which exerts landward pressure against the coast range mountains) and the warmer low pressure system in the adjacent Willamette Valley. Progressive heating of the valley air mass during the day results in thermal updraft followed by onshore winds that blow inland along the coast. The northerly and onshore winds typically persist in the South Slough estuary through the night at lower intensity.

Rainfall is conveyed rapidly through the system of streams and creeks that drain the South Slough watershed. For example, time-series records of daily rainfall and continuous measurements of several water parameters (at a NERR SWMP station) illustrate the effects of pulsed freshets on the shallow riverine Winchester Creek tidal channel. Intense rainfall delivered over several days (9-13 & 23-25 Jan 2000)

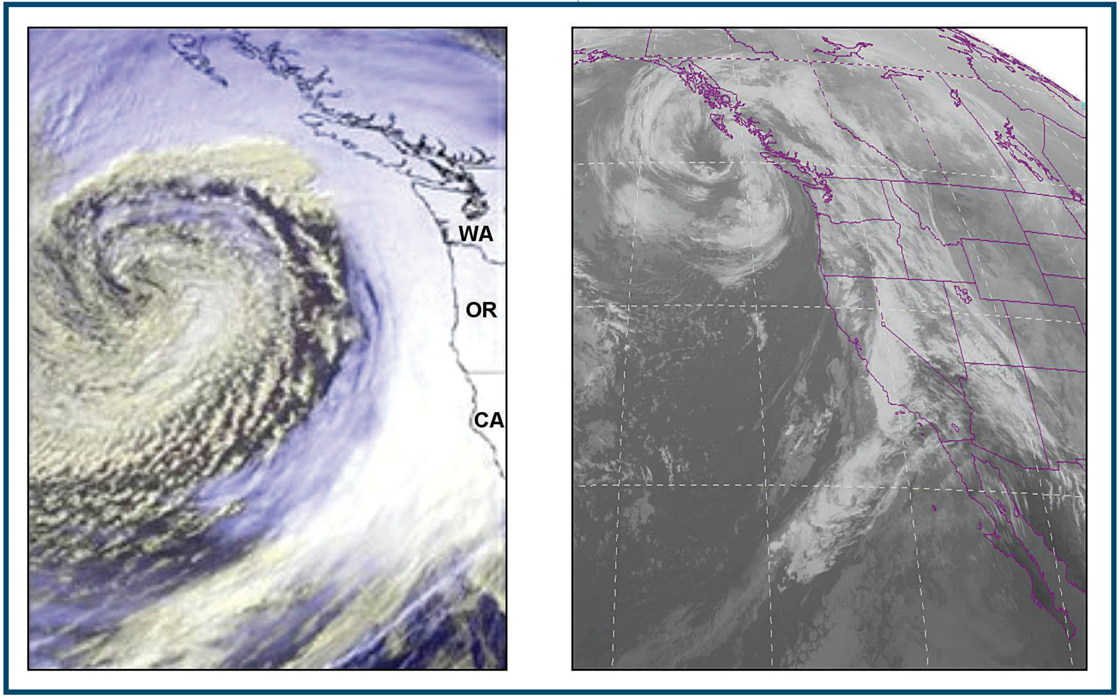


Figure 2.8. Satellite image of a cyclonic winter storm along the Pacific Northwest coast (from NOAA-CoastWatch).

resulted in sharp peaks in the daily discharge of freshwater from Winchester Creek (Figure 2.9). These short-term freshets washed through the shallow tidal channel and had dramatic impacts on a series of estuarine water parameters (Figure 2.10). In the absence of freshets, specific conductivity values during early January 2000 fluctuated directly between 0 to 28 mS cm^{-1} with the semi-diurnal cycle of flood and ebb tides. Background pH values were also driven by the tides and oscillated between 6.7 (low tide) and 7.7 (high tide) while turbidity values were low (<30 NTU). Onset of the freshet (10-13 and 23-24 January) caused specific conductivity values to abruptly decrease to 0 mS cm^{-1}, pH values to drop to <6.25, and dissolved oxygen values to become less variable and decoupled from the tides. Temporary spikes in turbidity were also observed (Figure 2.10). These disruptions of water column conditions lasted for 3-4 days until the rains subsided and the tidal channel environment was once again driven by the tidal cycle.

2.3 Soils in the South Slough Watershed

Surface sediments in the South Slough watershed and estuarine tidal basin are derived from several sources including terrestrial runoff, oceanic deposition, and biotic origins (Wilson, 2003). Relatively shallow soils have formed within the sediments throughout the watershed landscape, and the rounded hills, ridges, and valleys have moderate to steep slopes (10-60%) that are prone toward erosion and periodic landslides. The mosaic of different substrata units typically appear as a complex of mineral and organic soils that occur in close association with geomorphic and hydrographic features such as stabilized hillsides, eroding banks, stream beds, flood plains, toe slopes, and terraces.

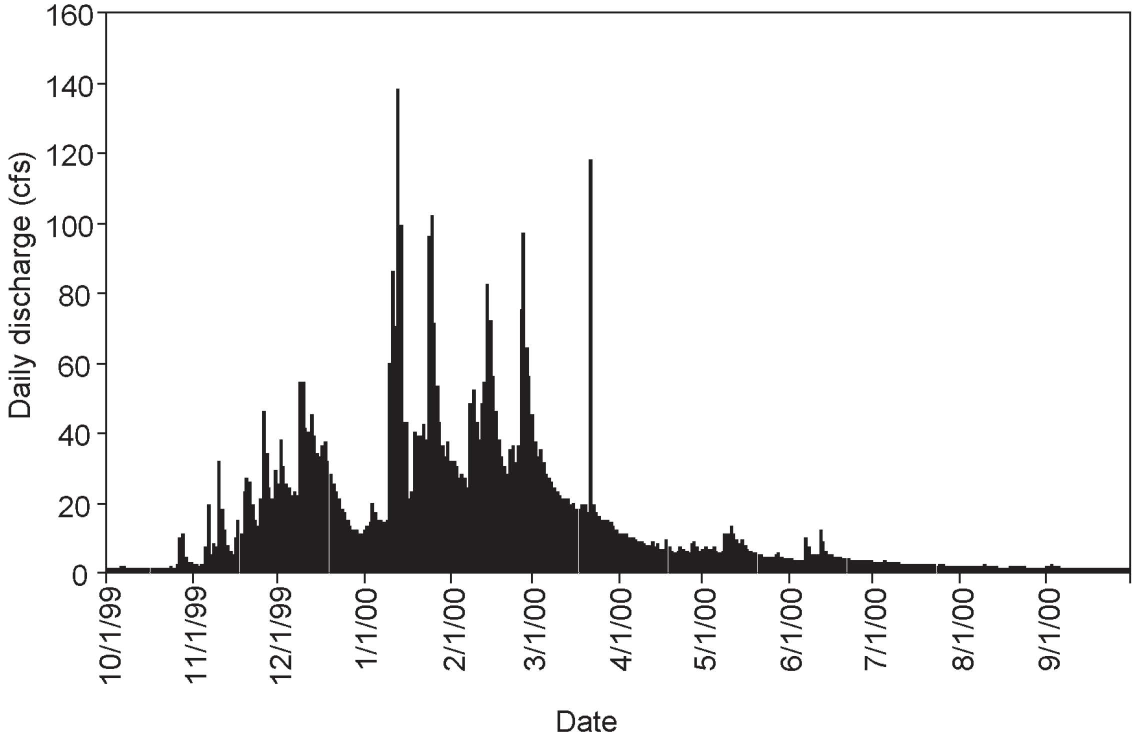


Figure 2.9. Pulsed discharge of freshwater inputs from Winchester Creek, South Slough estuary, OR. Values show daily discharge in cubic feet per second (cfs) during water year October 1999-September 2000 (from Coos County Water Resources Department).

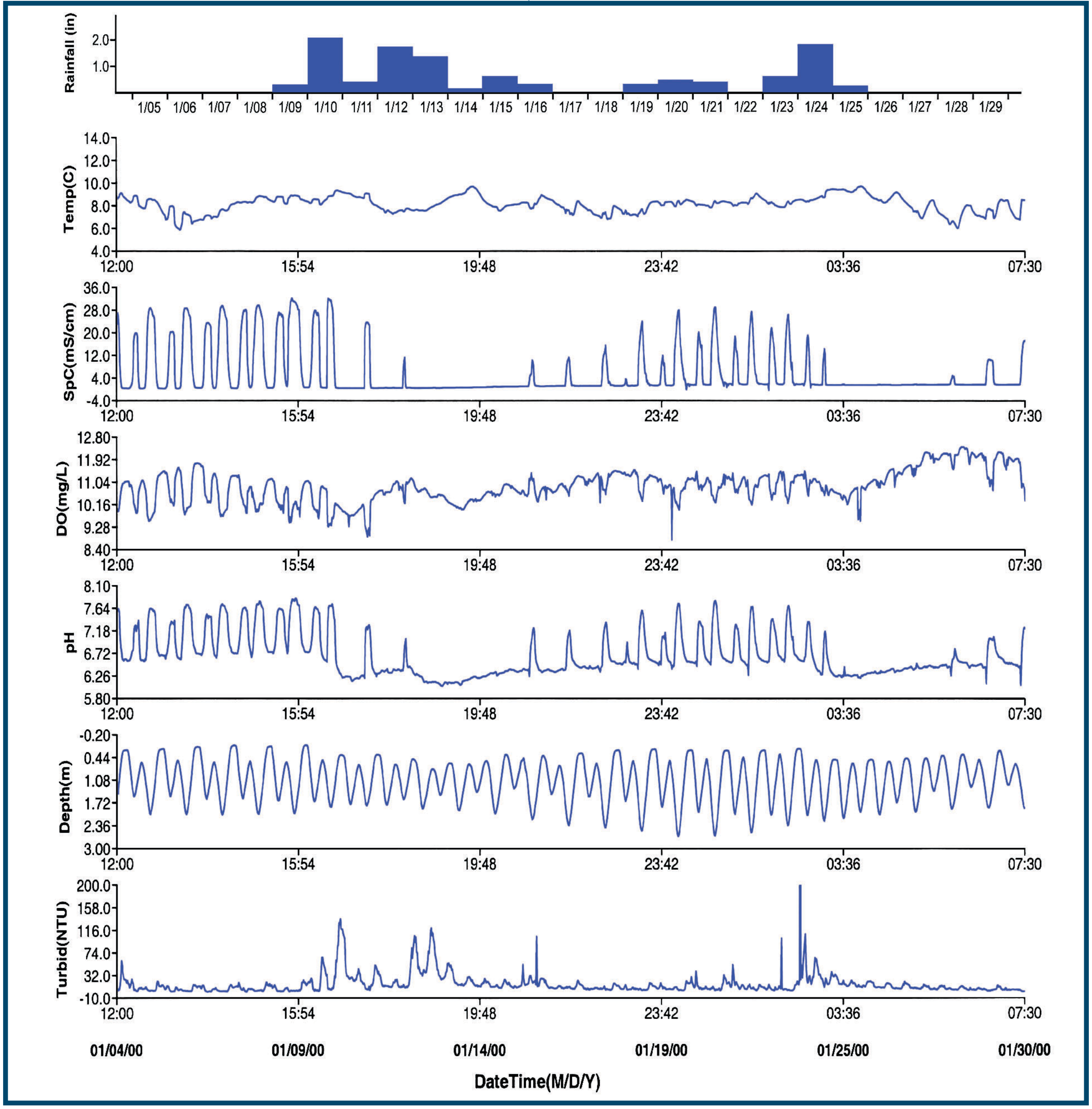


Figure 2.10. Effects of rainfall on several water quality parameters within the Winchester Creek tidal channel (NERR/SWMP Station SOS-WI). Rainfall data are from the North Bend Weather Station about 17 km away. Notice how heavy rainfall during 1/10-1/13 and on 1/24 had an immediate effect on specific conductivity, dissolved oxygen, pH, and turbidity levels. Cessation of rainfall allows the tidal creek to regain a strong tidal signal.

2.3.1 Soils in Upland Forested Areas

Sediments exposed on the low hills of the South Slough watershed are primarily soft loamy soils of the Templeton-Salander group, and sandy marine terraces of the Bullards-Bandon-Blacklock group (Haagen, 1989). The Templeton loams occur throughout the watershed and include a well-drained mixture of clay, silt, and sand that formed during the colluvial process from sedimentary materials that creeped down hillsides or washes and were deposited at the base of steep banks and toe slopes (see Figure 1.23). The surface layer of these dark rich soils is typically 30-60 cm thick, and the subsoil is usually a reddish brown or yellow clay loam. In contrast, the marine terrace sediments occur predominantly in the south-western region of the watershed and consist of well-drained or poorly-drained loams and sandy soils that formed as flat alluvial plains in the marine environment. The gray-brown surface layer is typically 25-30 cm thick with an 8-15 cm layer of organic matter, and the subsoils are a dark brown gravel and sandy loam. Water capacity for the Templeton loam is 20.3 to 44.5 cm and only 10.2 to 14.0 cm for the Bullards marine terraces (Haagen, 1989).

2.3.2 Riparian Areas, Wetlands, and Salt marshes

Watershed sub-basins located along the western side of the South Slough syncline (Seven Devils watershed sub-basins) are composed of uplifted, steeply-dipping, thrust faulted hills that reach topographic elevations of 60-110 m above sea level. Three of these Seven Devils watershed sub-basins (Dalton Creek, Wasson Creek, and Theodore John Creek) contain first and second order tributaries that fall rapidly from the ridgetops until they reach topographic elevations of 9-12 m where they enter wide, east-west trending bottomlands that transport freshwater and sediments directly into Winchester Creek and the South Slough estuary. Surface soils in these riparian areas, forested wetlands, and emergent freshwater marshes are typically sandy loams that are rich in organic materials. In contrast, the watershed sub-basins that drain the eastern side of the South Slough syncline (Cox Canyon and Tom's Creek) are composed of northwest-trending basins that are dissected by a series of thrust faults. Very little sediment from these basins is transported into the Winchester Creek tidal channel because the majority of sedimentary particles are deposited in upper sections of the canyons.

Soils in the tidally-flooded salt marshes of the South Slough estuary are classified as rich organic histosols (Haagen, 1989). These thick (up to 1.9 m) deltaic and unconsolidated soils typically consist of compacted clays, sand, and fine mud laid down in alternating layers of mineral sand/silt and organic peat materials. The marsh sediments occur at elevations of +1.6-2.3 m above NAVD and are completely inundated only by extreme high tides. A buried layer of coarse-grained sand overlies the organic peat at several locations in the estuary (Peterson and Darienzo, 1989; Nelson *et al.,* 1998) and provides evidence that the South Slough was last inundated by a tsunami about 300 years ago (Satake *et al.,* 1996). The unconsolidated histosol substratum is typically colonized by a wide variety of emergent hydrophytic vegetation that form fringing salt marshes along banks of the estuarine tidal channels (Graves, 1991). Suspended sediments and organic materials are transported into the salt marshes on flooding tides where they drop out of the water column and are deposited as new sediments. The histosol marsh sediments are typically saturated with water and have interstitial pore water salinities in the range of 5-15 psu that reflect the buffering capacity of marsh soils and their position along the estuarine gradient (Taylor, 1980).

2.3.3 Tideflats and Sandflats

Tidal flat sediments of the South Slough estuary are composed primarily of open sandflats and mudflats. Organic content of the mudflats is relatively high (8-18% of dry weight and 19.77 ppt; Baker, 1978) and they typically occur in regions of the estuary that experience low tidal energy. In contrast, organic content of the sandflats is much lower (1-2% dry weight and <0.1 ppt; Baker 1978) and they occur in areas of high tidal energy. These tideflat sediments are collectively known as fluvaquents that consist of sand or a matrix of silt, mud and organic layers at elevations that are normally covered by high tides. The fluvaquent mudflats and sandflats are typically devoid of emergent vegetation (Haagen, 1989), although they are frequently colonized by benthic diatoms, algal mats (*Vaucheria* and *Chaetomorpha*), and eelgrass beds (*Zostera marina* and *Z. japonica*).

Beach profiles are generally steep along the shoreline of the South Slough (9-15% slope). Sandy beach sediments increase in mean grain size with depth, and they decrease in mean grain size along the estuarine gradient (Younker Point 313.04 µm dia, Valino Island 282.07 µm, Ferrei Head 279.03 µm). Most beach sediments are well-sorted and have low sorting coefficients. The decrease in mean sediment grain size along the estuarine gradient most likely results from the gradual decrease in velocity of tidal currents and a reduction in their capacity to carry larger sediment particles (Arkett, 1980). Sediment temperatures are typically slightly warmer than the overlying water column.

Most intertidal sediments from the South Slough are a mixture of medium to fine-grained sand eroded from the shoreline terraces, and silts derived from fluvial inputs (Baker, 1978). Mineral elements of the unconsolidated mudflat substrata consist primarily of fine sediment particles that are predominantly silt (62.5 to 3.9 µm dia) and clay (3.9 to 0.2 µm). The high organic content of the mudflat substratum is contributed by decaying plant and animal tissues, fecal materials, detritus, diatoms, bacteria, and flocculants. Anaerobic conditions often exist a few cm below the sediment surface, and sulfate-reducing bacteria break down the organic materials and produce hydrogen sulfide.

Much of the mud, silt, and clay within the estuarine tidal basin enters South Slough from Coos Bay and the nearshore Pacific Ocean during flood tides (Wilson, 2003). Tidal currents and local winds re-suspend the fine materials and carry them long distances in the highly turbid waters. Suspended sediments with particle diameters of 20-30 µm are deposited when current velocities decrease to 0.1 cm s^{-1} (Hjulstrom, 1935; Sundborg, 1956). Relationships between sediment re-suspension, transport, and deposition vary with characteristics of the sediment particles (*i.e.,* specific gravity and size), current velocities, and the depth, salinity, and density of the estuarine water mass (Simenstad, 1983). Alternating layers of mineral and organic material are deposited on the tideflats of the South Slough estuary in complex patterns that reflect local variability in hydrodynamic energy.

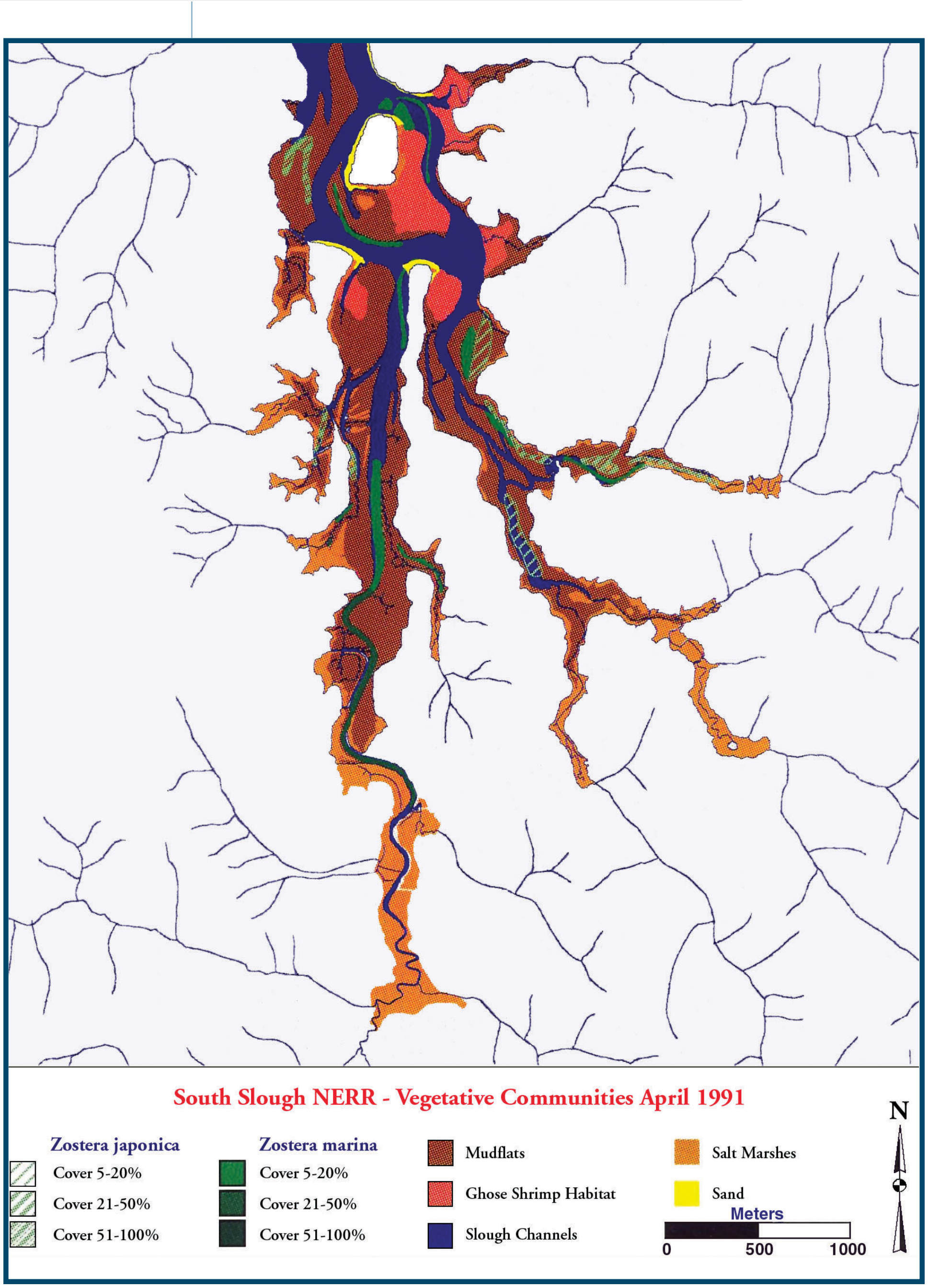


Figure 2.11. Spatial distribution of mudflats, sand, eelgrass (*Zostera marina, Z. japonica*), salt marshes, ghost shrimp habitat, and channels within the South Slough NERR; April 1991.

Tidal flat landforms within the South Slough are typically dissected on a meso-spatial scale (1-20 ac) by a dendritic network of shallow drainage channels. These channels function as two-way corridors for movement of water and sediments; they drain and remove water as the tide drops, but also fill and inundate the tideflats as the tide rises and spills over the shallow banks. As a consequence, lower regions of the tidal creeks convey larger volumes of water, experience greater current velocities, and often contain more dense sediment particles. As tidal waters inundate the upper region of the mudflats, current velocities decrease, the carrying capacity of the water is further diminished, and the finer-grained particles are deposited. These tidal flat landforms represent a dynamic balance between continual erosion and deposition as sediments are re-suspended, transported, and deposited with every flood and ebb of the tide.

Low gradient sandflats and sand bars are also a prominent feature of the South Slough tidal basin, particularly on the inside of major bends in the tidal channel in the northern and mid regions of the estuary (*i.e.,* Indian Point, Younker Point, Ferrei head, western side of Valino Island, Long Island Point; Figure 2.11). Sandflats interspersed with mud also occur within the deltaic littoral region at the mouth of Elliott Creek. Sandflats in intertidal areas of the basin are composed primarily of medium-grained sand particles (0.074 mm). These sandy sediments are derived largely from land sources and erosion of nearby cliffs. The sand particles are sorted, transported by the process of saltation along the bottom, and formed into sandbars by relatively swift tidal currents. Current velocities of over 1 ms^{-1} commonly occur in the South Slough and they generate ripple formations on the open sandflats. Sand ripples near Valino Island typically have crests 5-7 cm in height that are separated by 20 to 70 cm (Figure 2.12). Larger-scale sand waves sometimes occur in the deeper tidal channels with greater crest heights (20-30 cm) and increased distance between crests (1-3 m). Similar types of sand ripples occur on several different spatial scales within other estuarine tidal basins that experience swift tidal currents (Reineck, 1978; Reise, 1985). Migration of the sand ripples is directly related to increased current velocity. For example, current velocities of 10 cm s^{-1} cause sand ripples to move 3-4 cm hr^{-1} while 50 cm s^{-1} tidal currents can cause ripple displacement of 80 cm hr^{-1} (Reise, 1985).

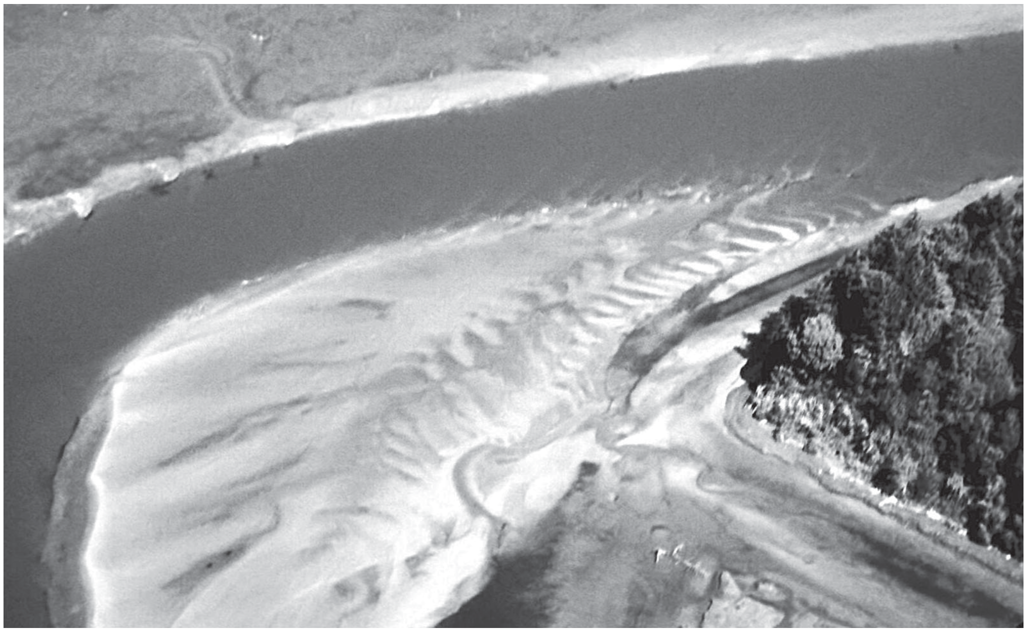


Figure 2.12. Intertidal sand ripples along the southwestern shoreline of Valino Island, South Slough NERR, OR.

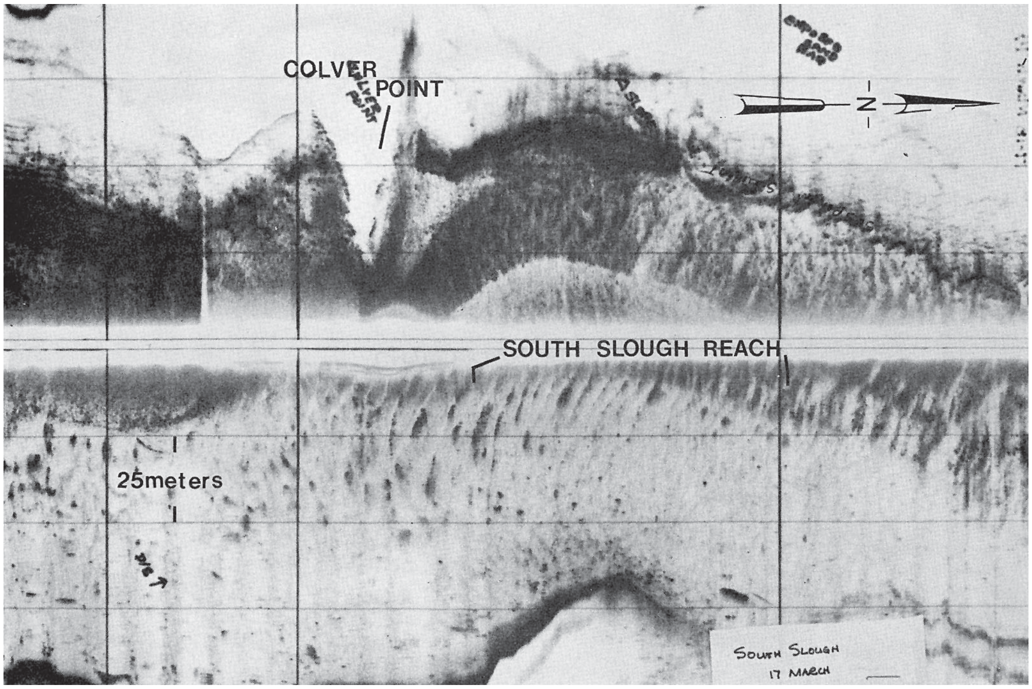


Figure 2.13. Side-scan sonogram of subtidal geomorphic features within the northern region of the South Slough estuary. Note the northward migration of sand ripples near Colver Point (from Hartman, 1976).

2.3.4. Subtidal Channel Sediments

Subtidal bottom sediments have not been surveyed extensively within the South Slough estuary. Hartman (1976) used side-scan sonar to map subtidal geomorphic features within the Charleston navigation channel and the northern region of the South Slough. Sonograms revealed distinctive sand waves in the South Slough near Collver Point (Figure 2.13), and grab samples confirmed that the bottom consisted of sandy sediments and shell rubble. The sand waves move predominantly northward, with the exception of intertidal sand ripples immediately south of Collver Point which migrate southward.

The spatial pattern of sediment distribution is determined by variability in the velocity and direction of tidal currents, freshwater inputs, and sediment sources. Coarse sand, shell rubble, and mud generally occur in the deep channels in the northern marine-dominated region of the South Slough estuary, and unconsolidated sands and mud occur in the shallow subtidal channels in the middle and riverine regions.

Changes in current velocities, current directions, sediment loads, and the density of water masses results in the deposition of sediments that vary spatially and temporally throughout the estuary. Minimum sediment particle sizes typically occur along the estuarine turbidity maximum where the upstream flooding of tidal currents is counterbalanced by the downstream flow of river currents (Arthur and Ball, 1979; Cloern, 1979). Location of the estuarine turbidity maximum changes within the South Slough estuary in response to variability in seasonal riverine discharge, and generally occurs in the region from the Hinch Road bridge to the northern section of Lattin Dike. Mixing of riverine and saline waters results in flocculation of fine aggregate particles of clay and organic detritus, and these flocculant materials settle out of the water column during slack tides. The majority of fine aggregate materials originally deposited within the estuarine turbidity maximum region are re-suspended and redistributed during flood or ebb currents (Simenstad, 1983).

2.4 Hydrology of the South Slough Watershed

The drainage area for the South Slough watershed covers about 7,932 ha. The tidal waters of the estuary receive freshwater inputs from the Joe Ney, Winchester, and Sengstacken sub-systems (Figure 2.14). The western (Winchester) arm of the estuary is fed by the Winchester Creek drainage system (2,468 ha) which provides the largest source of freshwater input. The eastern (Sengstacken) arm receives freshwater inputs from John B. and Talbot Creeks (combined drainage 983 ha), followed further downstream by inputs from Elliott Creek (799 ha). The west and east arms meet immediately south of Valino Island, and the estuary receives additional freshwater input from Day Creek (230 ha) and Joe Ney Slough (1,308 ha) on the east side and from Hayward and Farley Creeks (321 ha) on the west side. Freshwater inputs are highly seasonal and range between 0 to 0.6 m^3s^{-1} for the small creek systems (Day, Hayward, Farley Creeks), between 0.1 and 2.5 m^3s^{-1} for the intermediate creeks (John B., Talbot, Elliot, Joe Ney Creeks), and 0.2 and 4.8 m^3s^{-1} for Winchester Creek (Juza, 1995; see Figure 2.9). Total combined freshwater inputs vary seasonally from about 0.3 m^3s^{-1} in August to 6.6 m^3s^{-1} in February for the entire South Slough drainage basin (Harris *et al.,* 1979).

2.4.1 Principal Streams and Freshwater Inputs

Over 225 km of streams convey freshwater within the South Slough drainage basin (Figure 14). Stone (1987) collected physical and biotic survey information for over 113 km of streams and creeks that discharge into the South Slough estuary. Six perennial streams and over 30 intermittent creeks provide a highly seasonal source of freshwater input. The riverine region of the estuary is categorized as a 5th order tidal channel, and the 4th order streams meander slowly through the low bottomlands that drain into the Winchester and Sengstacken arms of the South Slough. These 4th order streams typically contain extensive freshwater marshes, particularly in the low lying deltaic stretches where they flow through forested wetlands (predominantly red alder: *Alnus rubra*), skunk cabbage (*Lysichiton americanum*), cattails (*Typha latifolia*), and marshes dominated by slough sedge (*Carex obnupta*) and reed canarygrass

Primary Freshwater Streams and NERR/SWMP Monitoring Stations

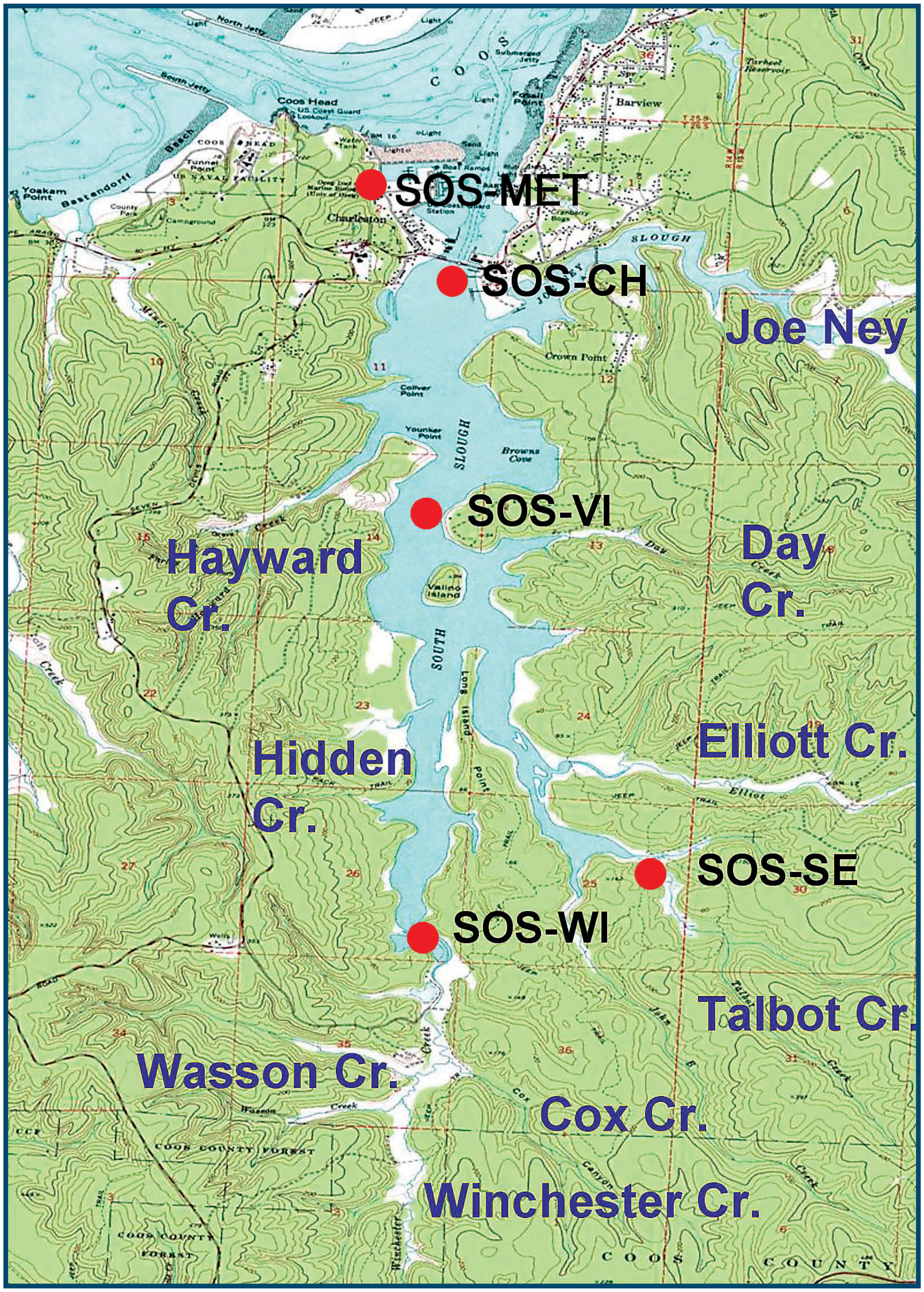


Figure 2.14. Location of primary freshwater streams and NERR/SWMP monitoring stations in the South Slough estuary, OR. SOS-VI: Valino Island; SOS-WI: Winchester Creek; SOS-SE: Sengstacken (Talbot Creek); SOS-MET: Meteorologic Station.

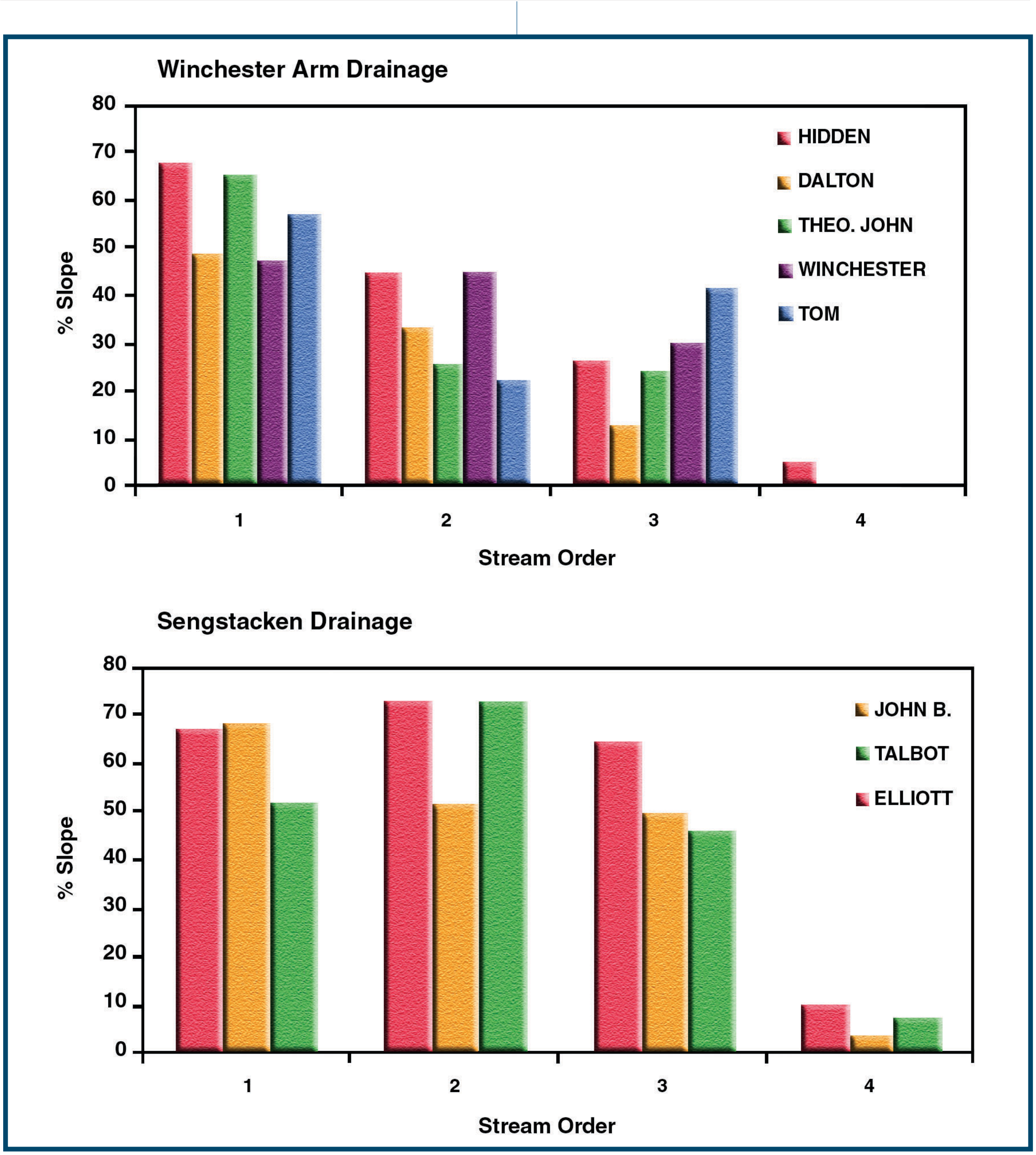


Figure 2.15. Hill slopes adjacent to stream beds within the Winchester and Sengstacken systems, South Slough watershed (adapted from Stone, 1987).

(*Phalaris arundinacea*). Maximum creek discharge occurs through Winchester Creek, and most of the 1st and 2nd order streams remain wet throughout the summer (June-September) with flow rates of <0.028 to 0.056 m^3s^{-1} (Stone, 1987).

The majority of 1st order streams within the South Slough watershed occur within very steep valleys with slopes of 50-70% (Figure 2.15). Stream gradients of 2.9-4.1% and greater are common at the headwall areas of watershed sub-basins, and they decrease to 1.9-2.1% and less at the lower elevations as the streams approach the head of tide. Hill slopes adjacent to stream beds in the Winchester arm drainage system are characterized by a gradual decrease from 48-68% for the 1st order streams to 12-42% for the 3rd order streams, followed by a steep drop to 0-5% for the 4th order streams and creeks. In contrast, hill slopes remained high for the 1st, 2nd, and 3rd order streambeds in the Sengstacken arm drainage system and then dropped to 4-10% for the 4th order streams and creeks. These geomorphic differences in hill slopes are directly associated with differences in the sedimentary geology on the west and east sides of the South Slough syncline (see Figure 2.2). Streams on the west side cut primarily through steeply-dipping Empire Formation sandstone and Bastendorf

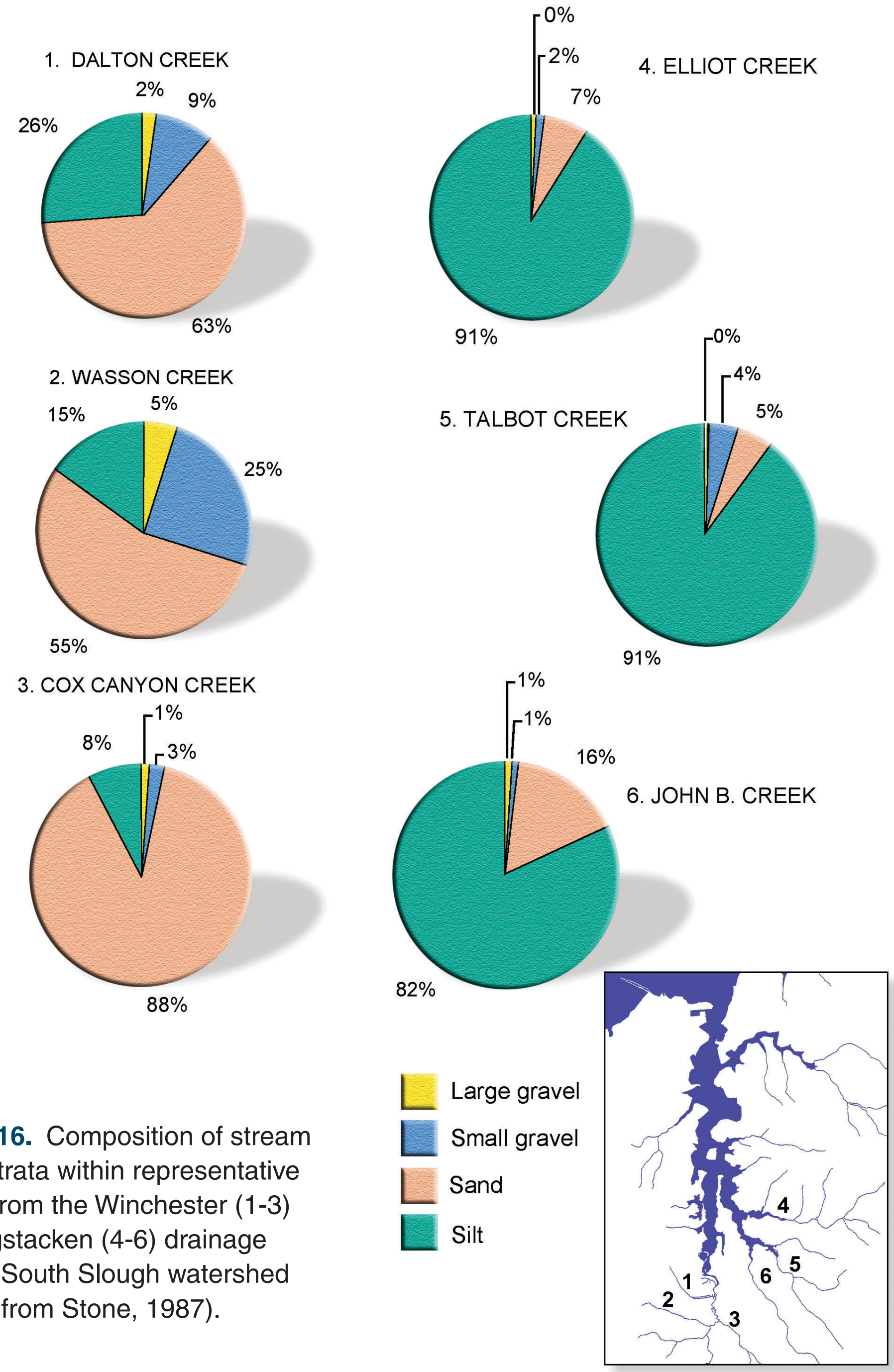


Figure 2.16. Composition of stream bed substrata within representative streams from the Winchester (1-3) and Sengstacken (4-6) drainage systems, South Slough watershed (adapted from Stone, 1987).

shale, while the eastside streams cut through elevated marine terraces composed of Coaledo Formation siltstone and mudstone. Coal outcrops can be observed in many of the 1st order streams on the eastern side of the South Slough watershed where they are exposed as rocky blocks and gravel (Stone, 1987).

Streambeds within the South Slough watershed are composed predominantly of unconsolidated sand, silt, and gravel (Figure 2.16). Some of the steep 1st order streams also contain boulders, cobble, and a few outcrops of bedrock. Substrata in the westside streambeds are predominantly sand, silt, and small gravel, while silt is the most abundant substratum in the eastside streams. These differences in streambed substrata also reflect the underlying geology of the watershed drainage basin. Streams located on both sides of the watershed often contain large amounts of woody material and organic debris as a sub-dominant substratum (Stone, 1987).

Red alder (*Alnus rubra*) and Sitka spruce (*Picea sitchensis*) are currently the dominant overstory trees within the riparian areas, and salmonberry (*Rubus spectabilis*) is the dominant understory species (Sheridan, 2001). This is a substantial change since 1986 when Douglas-fir (*Pseudotsuga menziesii*) was the dominant overstory species (Stone, 1987). Dense understory vegetation produces shade for substantially all stream beds, and stream bank stability was generally very good to excellent with the majority the bank surfaces covered by vigorous vegetation or protected by boulders, rubble, or bedrock (Stone, 1987; Denike *et al.,* 1992). Short reaches of the Winchester Creek drainage system provide spawning habitat for anadromous fish, and several species of fish are commonly observed in the lower reaches of most streams and creeks.

Freshwater inputs into the South Slough estuary are markedly seasonal (see Figure 2.9). Daily stream discharge is measured at an automated gauging station located above the head of tide on Winchester Creek (operated jointly by the South Slough NERR and the Coos County Water Resources Department since 1991). Inputs of freshwater are low (<8 cfs) during the dry season from mid July through September, and then increase in November and December with the beginning of the wet season. Average stream discharge is about 35-40 cfs from December through March, with short-term peaks of >100 cfs during episodic storm events. These discharge events are tightly coupled with the intensity of rainfall, and they often result in pulsed freshets that have significant impacts on the physical environment of the riverine tidal channels (see Figure 2.10).

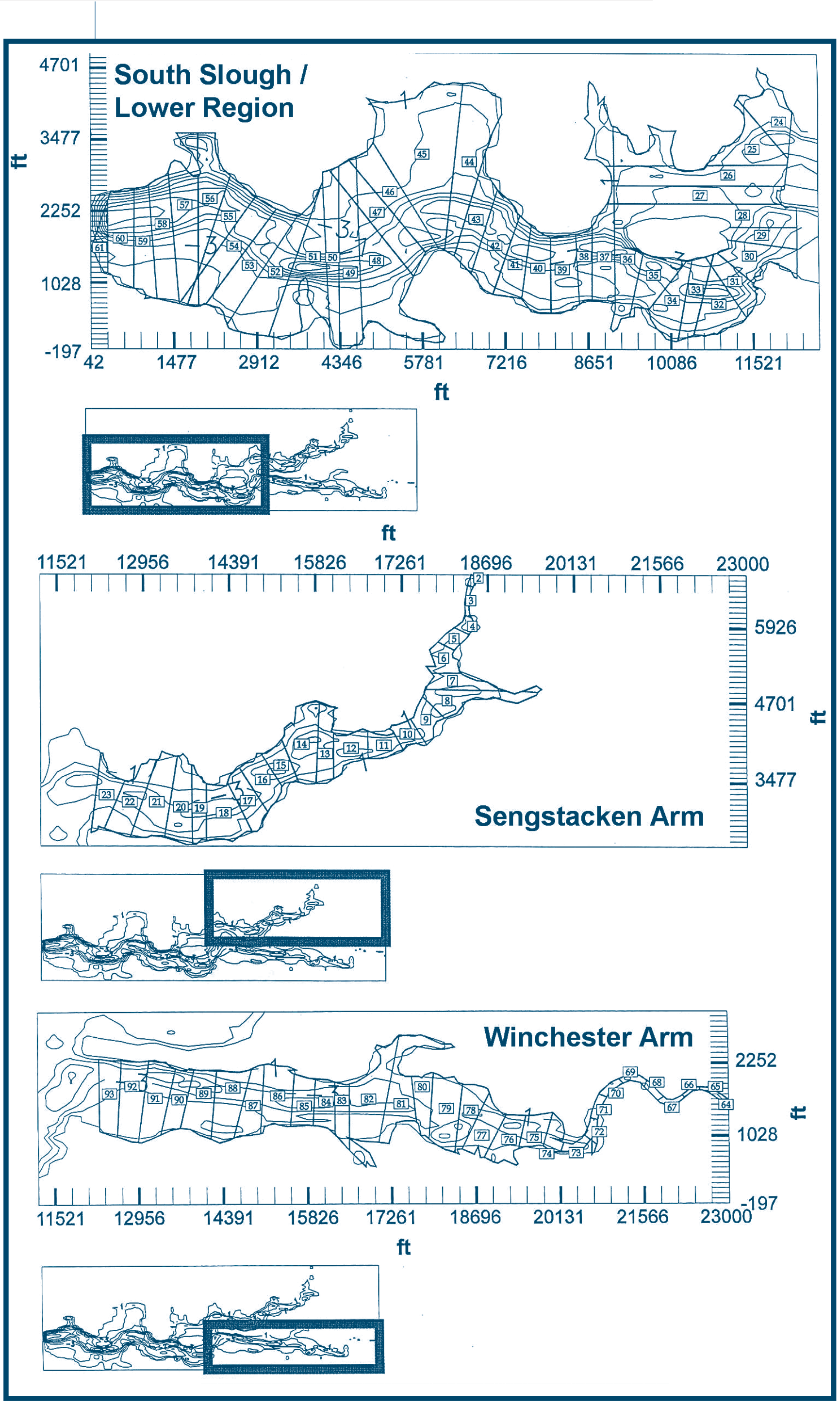


Figure 2.17. Estuarine bathymetry and delineations of hydrographic cells no. 1-93 for the South Slough estuary, OR (adapted from Juza, 1995).

2.4.2 Tidal Dynamics and Circulation Patterns

Tides in the South Slough estuary follow a semi-diurnal pattern with two high and two low tides per day (Figure 1.21). During the early and mid phase of flooding, the South Slough receives waters from the Coos estuary followed later by entry of flood waters directly from the ocean (Roegner and Shanks, 2001; Figure 2.18). During summer, the flood waters typically become slightly warmer (0.5 °C) and less saline (*ca.*1 psu) after they enter South Slough and mix with residual estuarine waters and freshwater in the tidal channels. The hydrological circulation pattern within the South Slough estuary is complex and still poorly understood (Juza, 1995; Roegner and Shanks, 2001).

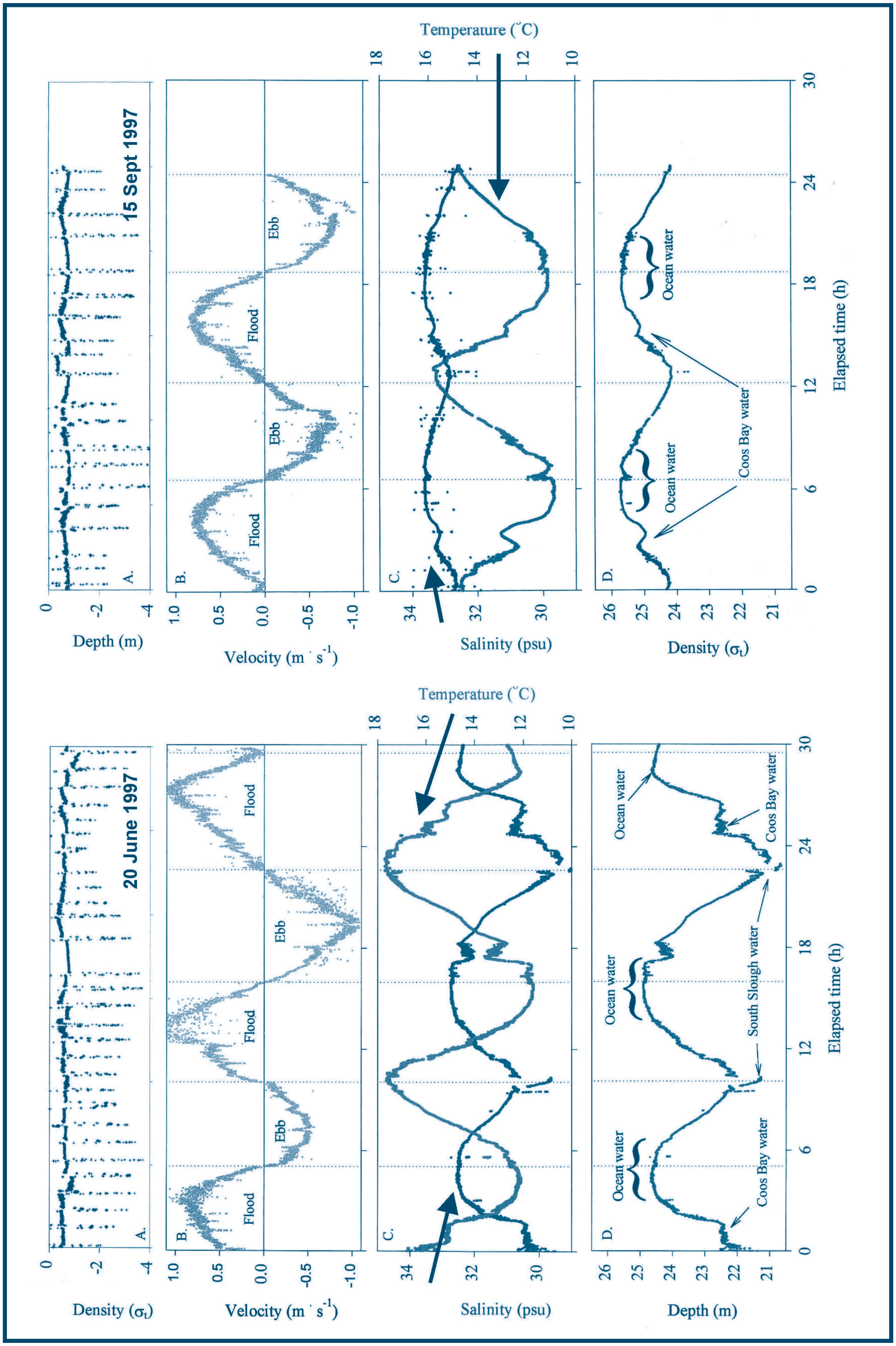


Figure 2.18. Tidally influenced dynamics in water depth, velocity, salinity, temperature, and density on 20 June and 15 September 1997, South Slough estuary, OR (adapted from Roegner, 1998).

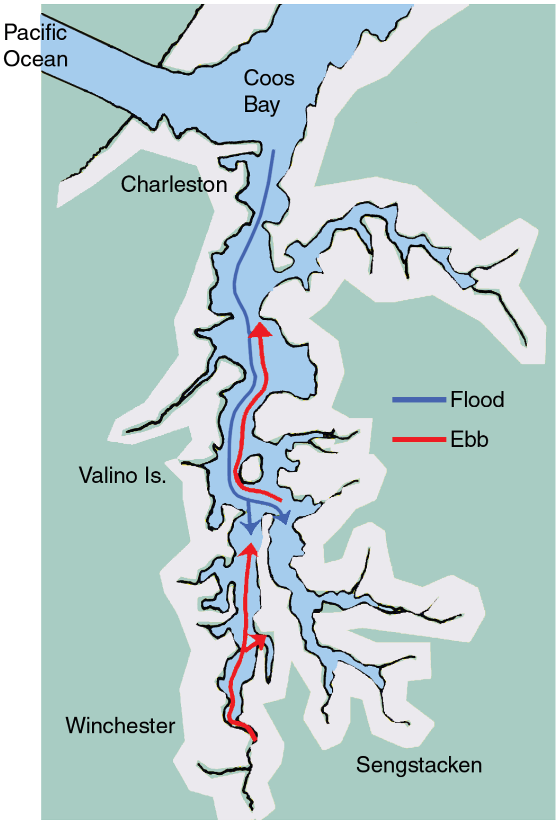


Figure 2.19. Deployment of drogues and dye to track movement of water masses in the South Slough estuary, OR. Blue line indicates extent of advective movement of tidal waters into the Sough Slough during a single flood event (3 hours). Red lines indicate advective tidal movement during a single ebb event (3-6 hours). Non-toxic fluorescent tracer dye was used to measure dispersion of tidal waters during advective flooding.

2.4.2.a Tidal Amplitudes and Timing

The maximum tidal amplitude measured at the mouth of the South Slough estuary is 4.02 m (NGVD). During 2000, the average tidal amplitude between Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW) was about 2.1 m, and the inequality between successive semi-diurnal high and low tides is generally 0.3 to 0.5 m. Strong offshore and southernly winds can enhance drainage of the South Slough estuary and result in lower than expected tides while northernly and onshore winds can raise tides above predicted levels. As the increase in tidal volume sweeps up the Oregon coast, the localized tidal wave enters the Coos estuary and proceeds through the South Slough. Comparisons of data from water level recording stations located at the mouth of the South Slough in Charleston, in the middle region at Valino Island, and in the riverine region at Winchester Creek illustrate differences in the maximum amplitude and timing of the tidal wave as it propagates along the estuarine gradient. High tide in Charleston occurs about 15 minutes before high tide at Valino

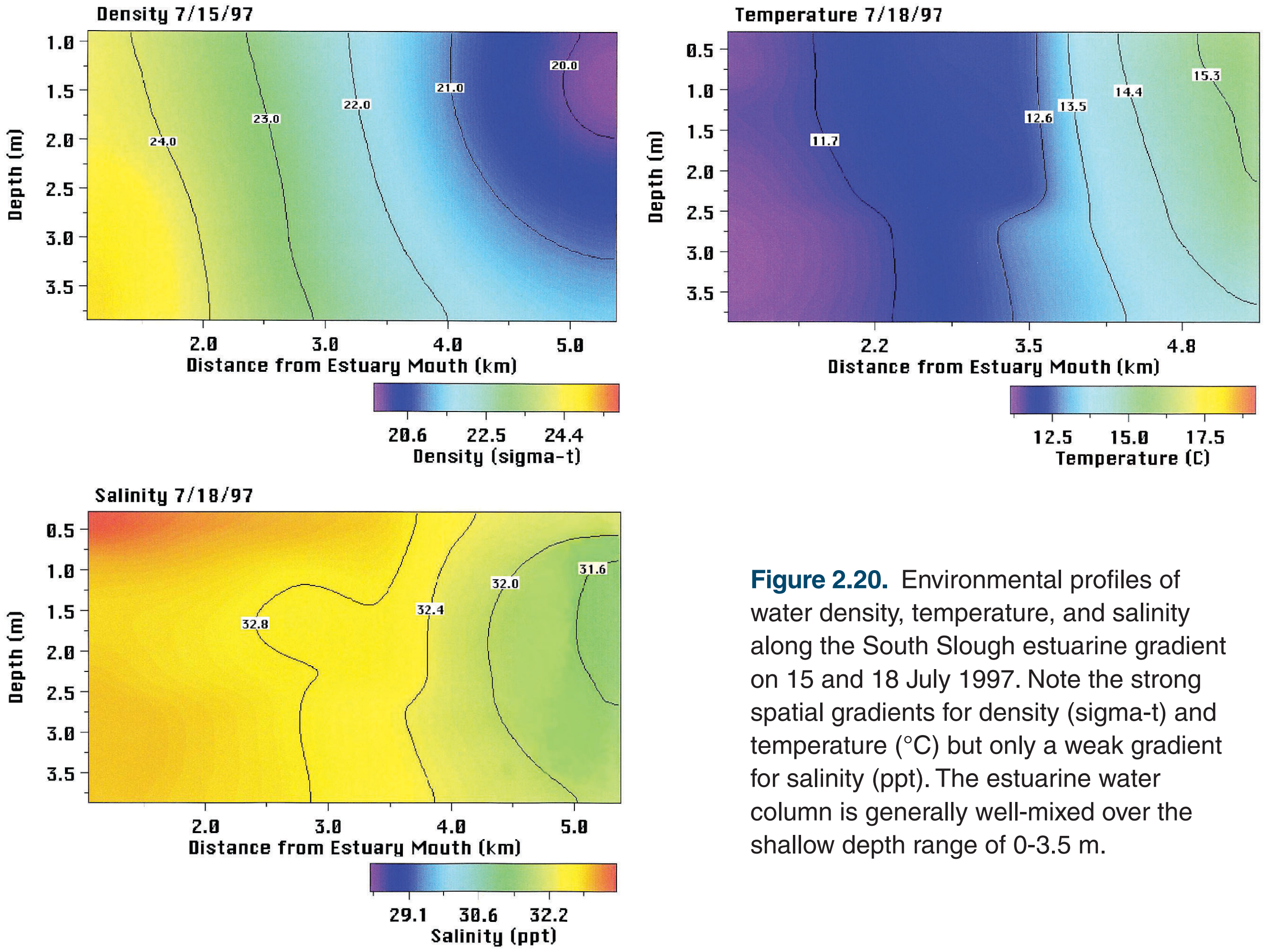


Figure 2.20. Environmental profiles of water density, temperature, and salinity along the South Slough estuarine gradient on 15 and 18 July 1997. Note the strong spatial gradients for density (sigma-t) and temperature (°C) but only a weak gradient for salinity (ppt). The estuarine water column is generally well-mixed over the shallow depth range of 0-3.5 m.

Island, and high tide in the riverine region lags behind Charleston by about 63 minutes. Maximum tidal amplitude is slightly greater at Valino Island (2.7 m) than Charleston (2.6 m), and reduced to about 2 m in Winchester Creek. The increase in tidal amplitude occurs midway up the estuary at Valino Island because the wave of tidal water is physically constricted along the sides and bottom as the channel narrows and becomes shallower.

2.4.2.b Tidal Currents, Circulation, and Flushing

Circulation within the South Slough tidal basin is strongly driven by tidal oscillations within Coos Bay and along the outer coast. Wells and Baird (1990) gathered bathymetric data and field calibration measurements for several fundamental physical variables over a 30 day period in 1990, and Juza (1995) compiled the information into a two-dimensional (longitudinal and vertical) hydrodynamic model for the tidal basin. For computational purposes, the estuarine tidal basin was divided into 93 cells, each 122 m in length (Figure 2.17). Maximum tidal velocities measured at the Charleston Bridge and Valino Island are nearly 1 ms^{-1} during peak flood and ebb tidal flows, and average current velocities are about 0.4 ms^{-1} (Wells and Baird, 1990; Roegner and Shanks, 2001; Figure 2.18). The South Slough estuary is well-mixed vertically (except during wet storm events) and experiences a strong instantaneous longitudinal salinity gradient (*ca.* 30-2 psu) and a weak temperature pattern (*ca.* 3-4 °C) along the length of the tidal inlet. During field calibrations fluorescent dye released within the Winchester arm was tracked over a period of 14 hrs and appeared in the Sengstacken arm after 2 tidal cycles. Juza (1995) modeled the longitudinal transport of tracer inputs and calculated that aqueous dye released at two upstream point sources (Winchester Creek and John B. Creek) is transported downstream through the estuary to Charleston Harbor after periods of 36 hrs.

Similarly, the residence time for water within the Winchester arm of the estuary is estimated at 1.3 ebb cycles (Wilson, 2003). Flushing time for the entire estuary is estimated at 6-8 tidal cycles, or about 3 days.

Advective tidal movement of water masses and flux of organic materials are important characteristics of the estuarine environment in the South Slough. Behavior of estuarine water masses has been observed by following the advective movements of drogues released at several locations in the estuary (Figure 2.19). Surface (individually marked oranges and grapefruit) and subsurface drogues (floats with sea-anchors) released at the mouth of the estuary (Charleston Harbor and beneath the Charleston bridge) were transported on flood tides a maximum distance of 5 km south to Valino Island and into the Winchester arm in a single tidal excursion (Rumrill, pers. observation). Conversely, drogues released near Long Island Point (Figure 2.19) on ebb tides were transported northward 4 km to the mouth of Joe Ney

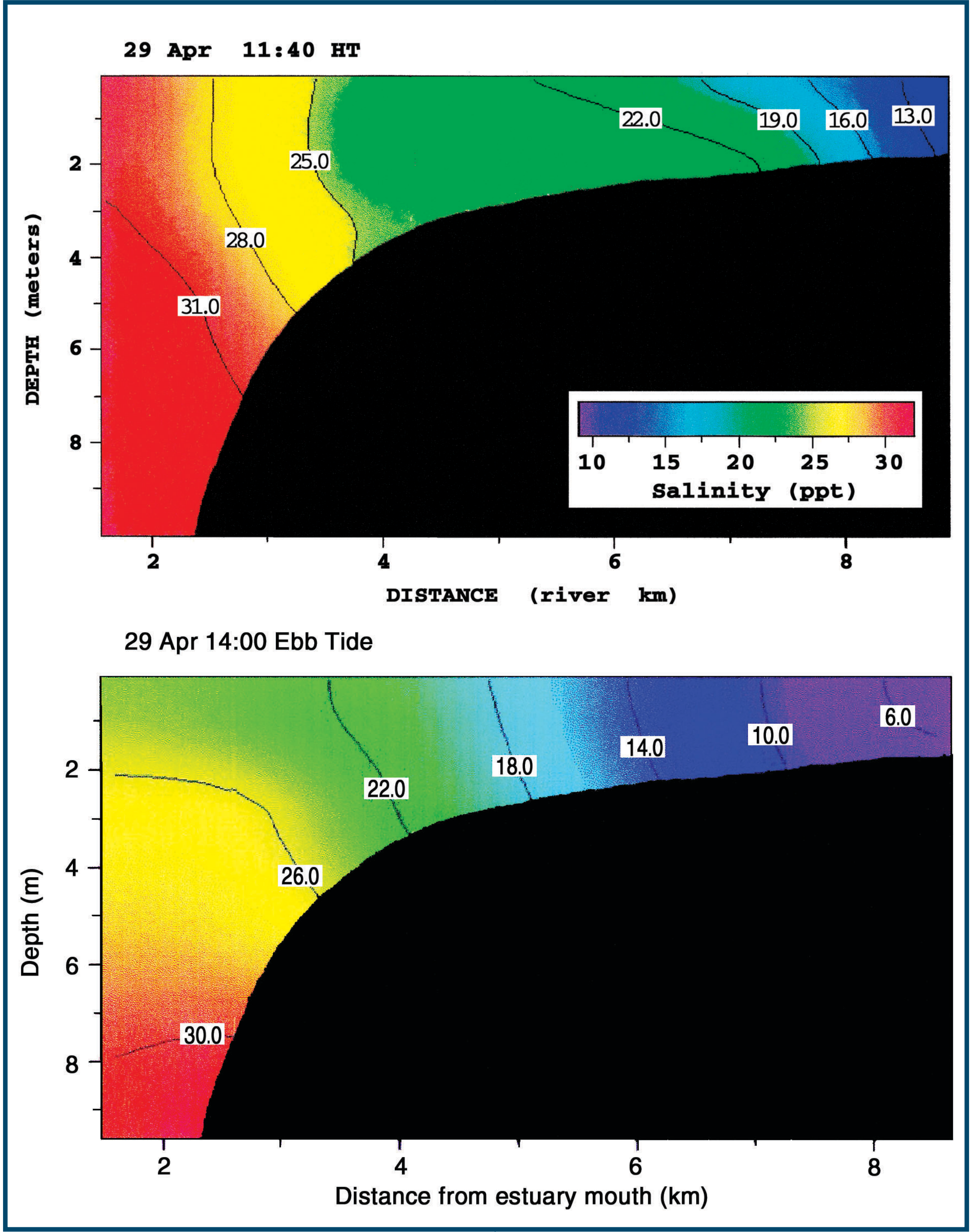


Figure 2.21. Salinity profiles at high and low tides along the South Slough estuarine gradient. Note formation of a distinct high tide salt wedge at a distance of 5-7 km, and break-down of the salt wedge at ebb tide.

Slough. These observations are consistent with measurements of tidal current velocities and model estimates of tidal flushing (Juza, 1995; Roegner and Shanks, 2001; Puls, 2002). The transport of drogues is also consistent with observations of the southward movement of floating wastewater from the Charleston fish processing plants on flooding tides. Drogues released in the southern region of the Winchester arm (Kunz marsh and Hinch Road bridge) were transported shorter distances; 62% of the drogues remained within 2.2 km of their initial release point after a period of 48 hrs (Figure 2.19).

2.5 Physiochemical Characteristics of the South Slough Estuary

Physiochemical characteristics of the estuarine water column vary considerably throughout the South Slough on a seasonal basis and with the semi-diurnal tides. The water column is usually well-mixed vertically, both near the mouth in the marine-dominated region (Harris *et al.,* 1979; Roegner and Shanks, 2001; Puls, 2002; see Figure 2.18) and in the riverine region. The water column may become stratified or partially stratified for short periods during heavy rainfall events. Extensive exchange of tidal waters occurs within the South Slough estuary during the daily flood and ebb cycle, however, and results in turbulent mixing and breakdown of vertical stratification of the water column.

Physical and biotic characteristics of the tidal waters in South Slough change markedly with tidal stage and are influenced strongly by conditions in the nearshore Pacific Ocean, in the greater Coos estuary, and by freshwater runoff that drains into the estuarine tidal basin (Roegner and Shanks, 2001). Strong latitudinal gradients exist along the marine to freshwater axis for several parameters including salinity, density, specific conductivity, nutrients, and chlorophyll concentrations (Figure 2.20), while weaker gradients exist for temperature, dissolved oxygen, and pH. A distinct salt wedge sometimes forms in the mid region of the South Slough estuary during flood tides (Figure 2.21) but the stratification dissipates as the shallow tidal waters are mixed and recede during the ebb. Tidal waters in the marine-dominated region of the estuary are strongly influenced by the nearshore ocean waters, and nutrients and chlorophyll are advected regularly into the South Slough on flooding tides. Conversely, characteristics of tidal waters from the middle and riverine regions of the estuary reflect a dynamic mixture of ocean waters and freshwater runoff. The spatial pattern of salinity, density, and temperature along the South Slough estuarine gradient varies directly with stage of the tide, and variability in biotic character of the water masses (phytoplankton and zooplankton populations) will operate in concert along the north-south trending tidal channel.

2.5.1 Temperature and Salinity Cycles

Measurements of water temperature and salinity (recorded at three permanent SWMP monitoring stations; see Figure 2.14) illustrate the typical seasonal cycle at several locations within the South Slough estuary. Relatively cold and highly variable saline conditions occur in bottom waters near Valino Island during the wet stormy season (December-February) when temperatures fluctuate between 8-12 °C and salinities are driven directly by the tidal cycle (4 and 30 psu; Figure 2.22). Slightly colder conditions occur during December-February in the riverine regions (Winchester and Sengstacken SWMP stations) where bottom water temperatures vary between 5 and 11 °C (Figures 2.23, 2.24). Salinities are highly variable during the wet winter season in both the Winchester and Sengstacken arms (0-20 psu) due to the low basin volume and highly episodic inputs of freshwater from Winchester, John B., and Talbot Creeks.

The cold winter is followed by gradual warming of the estuarine water during March-May when temperatures increase to 13-18 °C at Valino Island and to 14-23 °C at the Winchester and Sengstacken monitoring sites (Figures 2.22, 2.23, 2.24). Decreased freshwater inputs allow salinities to increase gradually (27 ± 4 psu) and become more stabilized during March-May at Valino Island. Salinities remain highly variable and exhibit an overall increase at the Winchester (*ca.* 1-25 psu) and Segstacken sites (*ca.* 1-22 psu).

During the dry summer season (June-August), average bottom water temperatures remain elevated around 15 °C at Valino Island and fluctuate between 10-21 °C with the ebb and flood of the tides (Figure 2.22). Salinity measurements are high and exhibit little tidal variability (31 ± 3 psu) at Valino Island during the summer, and they decrease and become more variable (30 ± 5 psu) during the fall (September-November). Water temperatures are also highest

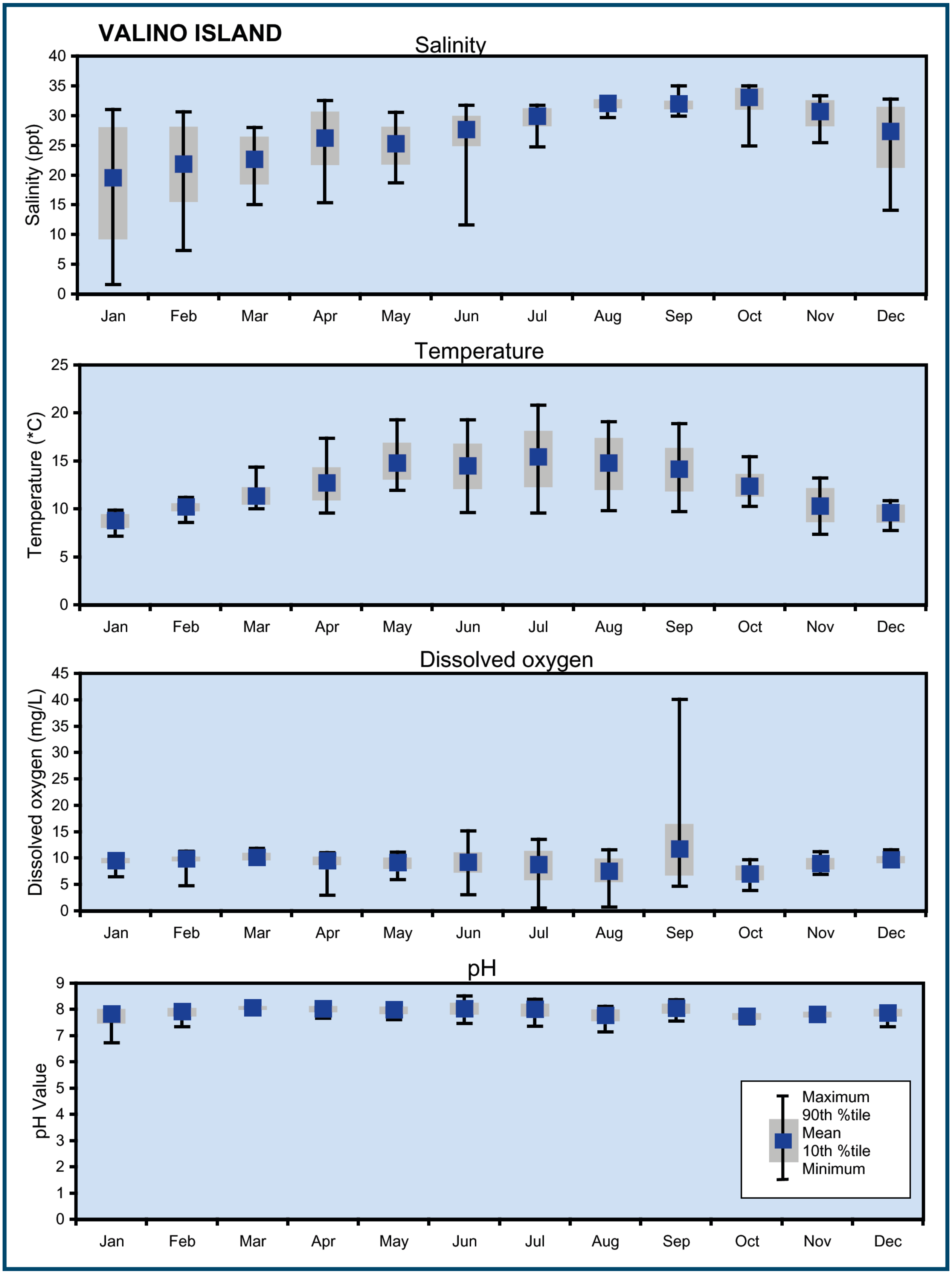


Figure 2.22. Annual cycles in salinity, temperature, dissolved oxygen, and pH at Valino Island, South Slough, OR (2000). See Figure 2.14 for location of NERR/SWMP Station SOS-VI.

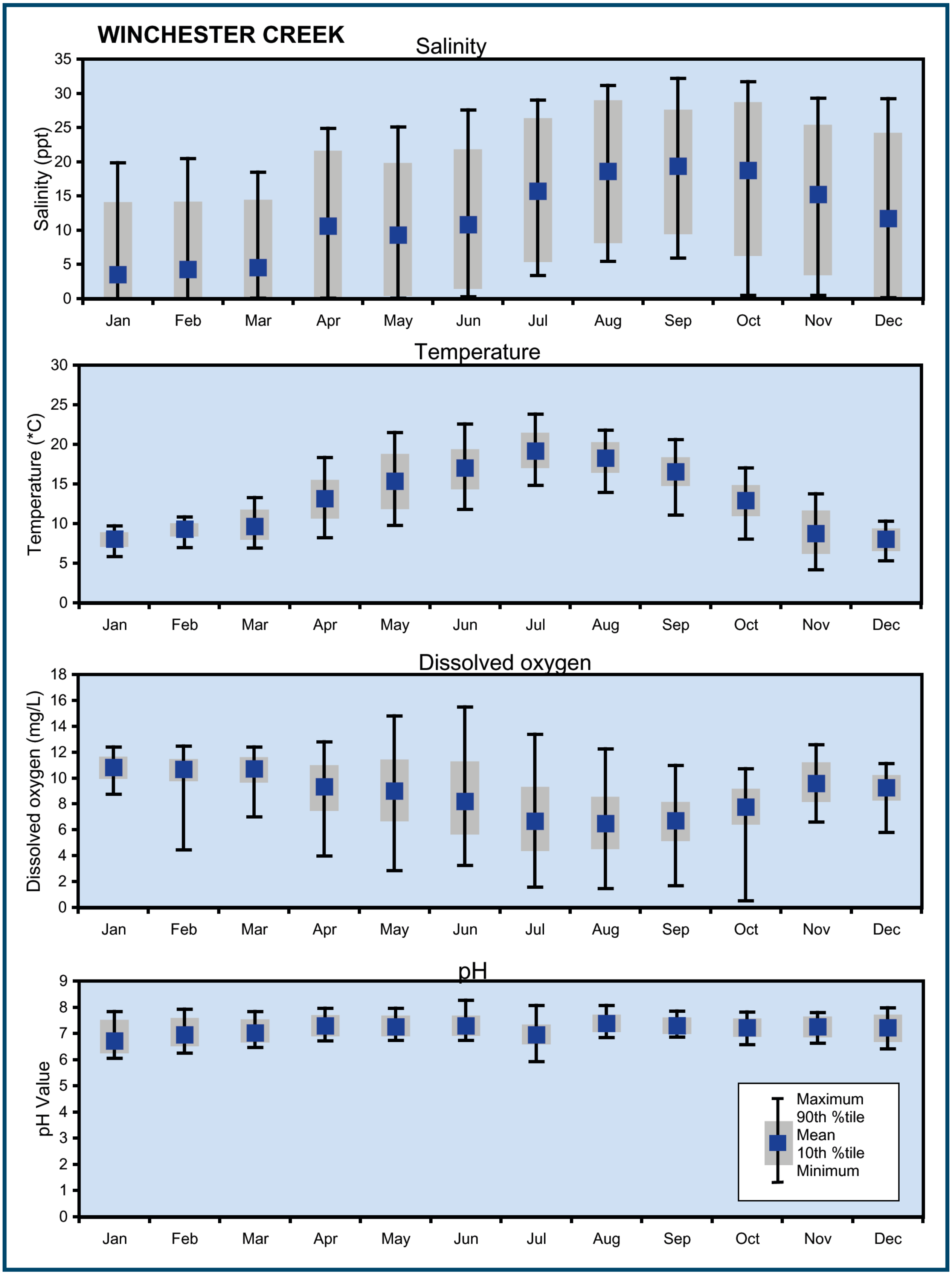


Figure 2.23. Annual cycles in salinity, temperature, dissolved oxygen, and pH in Winchester Creek, South Slough, OrR (2000). See Figure 2.14 for location of NERR/SWMP Station SOS-WI.

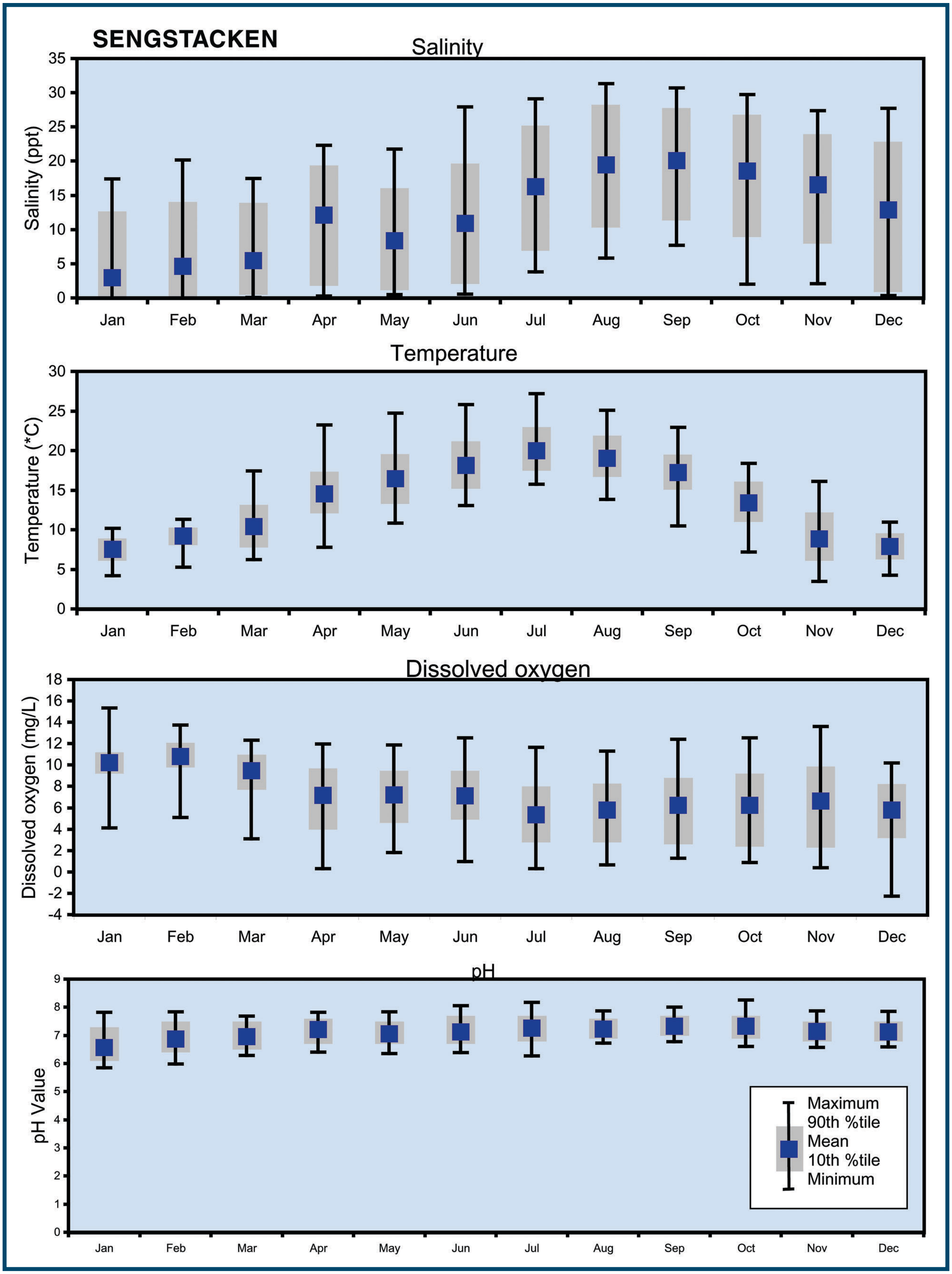


Figure 2.24. Annual cycles in salinity, temperature, dissolved oxygen, and pH in the Sengstacken arm of South Slough, OR (2000). See Figure 2.14 for location of NERR/SWMP Station SOS-SE.

in the riverine regions during summer months when they average about 17 ± 5 °C at the Winchester and Sengstacken sites (Figures 2.23, 2.24). Summer salinities increase and continue to fluctuate strongly with the tides at the Sengstacken (17-30 psu) and Winchester (7-30 psu) monitoring sites. During the fall months, temperatures decrease rapidly in the riverine region and salinities also decline, particularly after the first significant storms and rainfall events (typically November).

2.5.2 Dissolved Oxygen and pH levels

Concentrations of dissolved oxygen (DO) can greatly affect biotic communities and biogeochemical processes in tideflats, tidal creeks and estuarine tidal basins. DO concentrations (% saturation or mg/L) were generally high in the South Slough and fluctuated between 90 and 110% (8-10 mg/L) throughout the winter and spring seasons at Valino Island (Figure 2.22). Variability in DO concentrations increases dramatically in the summer and then decreases again in fall and winter. The lowest DO concentrations measured at Valino Island (10-40% Sat) are coincidental with low tides in summer, and the lowest average DO concentrations occurred in October (Figure 2.22). This seasonal cycle provides evidence that the water column is well-oxygenated in the marine-dominated region with very little to no likelihood of hypoxia. Dissolved oxygen concentrations showed a similar seasonal pattern in the riverine region at the Winchester monitoring site (Figure 2.23), but a dissimilar pattern at the Sengstacken site where they increased markedly in variability in late spring and remained highly variable throughout the summer and fall (Figure 2.24).

Annual measurements of pH levels in the estuarine bottom waters of the South Slough did not reveal a distinct seasonal pattern at any of the estuarine monitoring sites (Figures 2.22, 2.23, 2.24). Estuarine pH levels remained largely within 7.5 and 8.2 throughout the year in the tidal waters near Valino Island. Lower pH levels (>95% of the observations between pH 6.5 to 7.8) occurred throughout the year in the less saline waters at the Winchester and Sengstacken sites. However, pH measurements did vary strongly on a daily basis with the semi-diurnal tidal cycle at all monitoring sites in direct reflection of tidal changes in conductivity and salinity (*e.g.* see Figure 2.10).

2.5.3. Nutrients, Turbidity, and Dissolved Solids

Understanding of the seasonal and tidal dynamics of nitrogen and phosphorus concentrations is important in the South Slough because high levels of these nutrients can lead to over-enrichment and problems associated with eutrophication. Seasonal changes in inorganic nutrient levels have been monitored on a monthly basis along the estuarine gradient of the South Slough beginning in 2002 (Rumrill and Powell, 2005), and illustrate both temporal and spatial differences in the delivery of dissolved nutrients into the system. For example, concentrations of nitrate measured at low tide are typically greatest over the late summer and fall within the marine-dominated regions of the estuary, and they decrease within the mesohaline and riverine regions (Figure 2.25). In contrast, nitrate concentrations are fairly high and uniform throughout most of the estuary in winter during the period of peak freshwater inputs. These time-series data provide evidence of the oscillation between nutrient delivery from the nearshore Pacific Ocean in the dry season and from the creeks and streams in the wet season. Comparison of these recent nutrient values with those measured over two decades earlier (Browning, 1980) indicates that water quality conditions have remained fairly good, and that the South Slough estuary does not receive harmful levels of nutrient runoff from the adjacent uplands.

Fry *et al.,* (2001) also analyzed several biochemical indicators of nitrogen loading along the entire estuarine gradient of the South Slough including fully marine waters (Cape Arago) and freshwater creeks. Dissolved Inorganic Nitrogen (DIN) concentrations decrease along the estuarine gradient from 36 M at the mouth of the estuary to 18 M in the riverine tidal channels. These low DIN concentrations indicate that nitrogen loading is not excessive in the South Slough, and that flooding ocean waters are the principal source of nitrogen input into the estuary. Particularly low DIN concentrations of 5 M (1.9 M nitrate and 2.6 M ammonium) occurred in the beaver pond at Cox Canyon Creek that drains forested wetlands and a mixed coniferous-deciduous forest. These values are the lowest average DIN concentrations observed by Fry *et al.,* (2001) for 45 stations within four Pacific coast National Estuarine Research Reserves (Tijuana River, CA; Elkhorn Slough, CA; South Slough, OR; Padilla Bay, WA).

Fairly uniform ^{15}N values were observed within the South Slough for filter-feeding barnacles (*Balanus glandula*) and green macroalgae (*Ulva* spp.), consistent with the understanding that the estuarine water column is strongly dominated by input of marine waters. The ^{15}N values for Particulate Organic Matter (POM) were not significantly different from green algae ^{15}N values, providing further indication of the dominance by marine waters. By comparison, sediments throughout the South Slough estuary exhibited consistently lighter ^{15}N values than the other three bioindicators (barnacles, green macroalgae, and POM). Carbon:Nitrogen (C:N) ratios for green macroalgae, POM, and sediment increase along the South Slough estuarine gradient and are inversely correlated with DIN concentrations (Fry *et al.,* 2001).

Tidal waters of the South Slough estuary are characterized by episodic and short-term spikes in turbidity. Typical baseline levels of 8-12 NTU occur at the Valino Island site that are interrupted *ca.* 15-20 times per year by rapid increases to 50 NTU (and sometimes 200-300 NTU) that last for a few hours. Spikes in estuarine turbidity values are more frequent and of greater magnitude in the dynamic riverine region where baseline levels are about 20-30 NTU and spikes to 100-400 NTU occur on a frequent basis.

Total dissolved solids (TDS) have not been measured directly within the South Slough estuary. However, Wells and Baird (1990) used correlation analysis to estimate TDS levels from

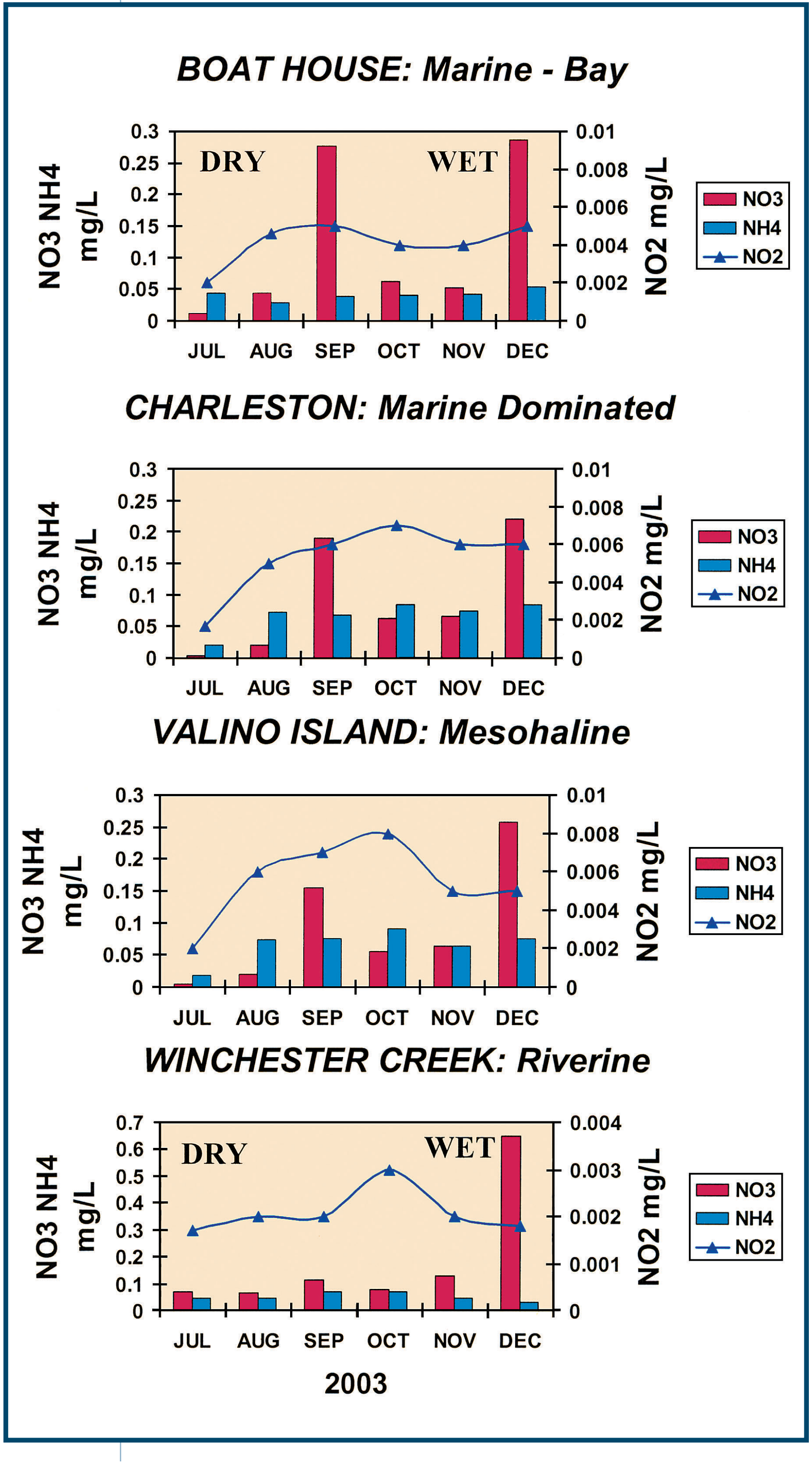


Figure 2.25. Spatial and seasonal changes in nutrient concentrations along the estuarine gradient of the South Slough. Concentrations of nitrate (NO_3), nitrite (NO_2) and ammonium (NH_4) decrease gradually from the marine to riverine regions during the dry season (Sep), but high concentrations of these nutrients occur throughout the estuary during the wet season (Dec). From Rumrill and Powell, 2005.

measurements of conductivity (Figure 2.26). Time-series estimates suggest that tidal flooding results in increased conductivity and elevated TDS levels, while ebb tides result in lower water conductivity and TDS levels. Consequently, estimates of TDS varied directly with tidal currents and ranged between 4,000 and 35,000 mg L^{-1} during Feb-Mar of 1990 (Wells and Baird, 1990).

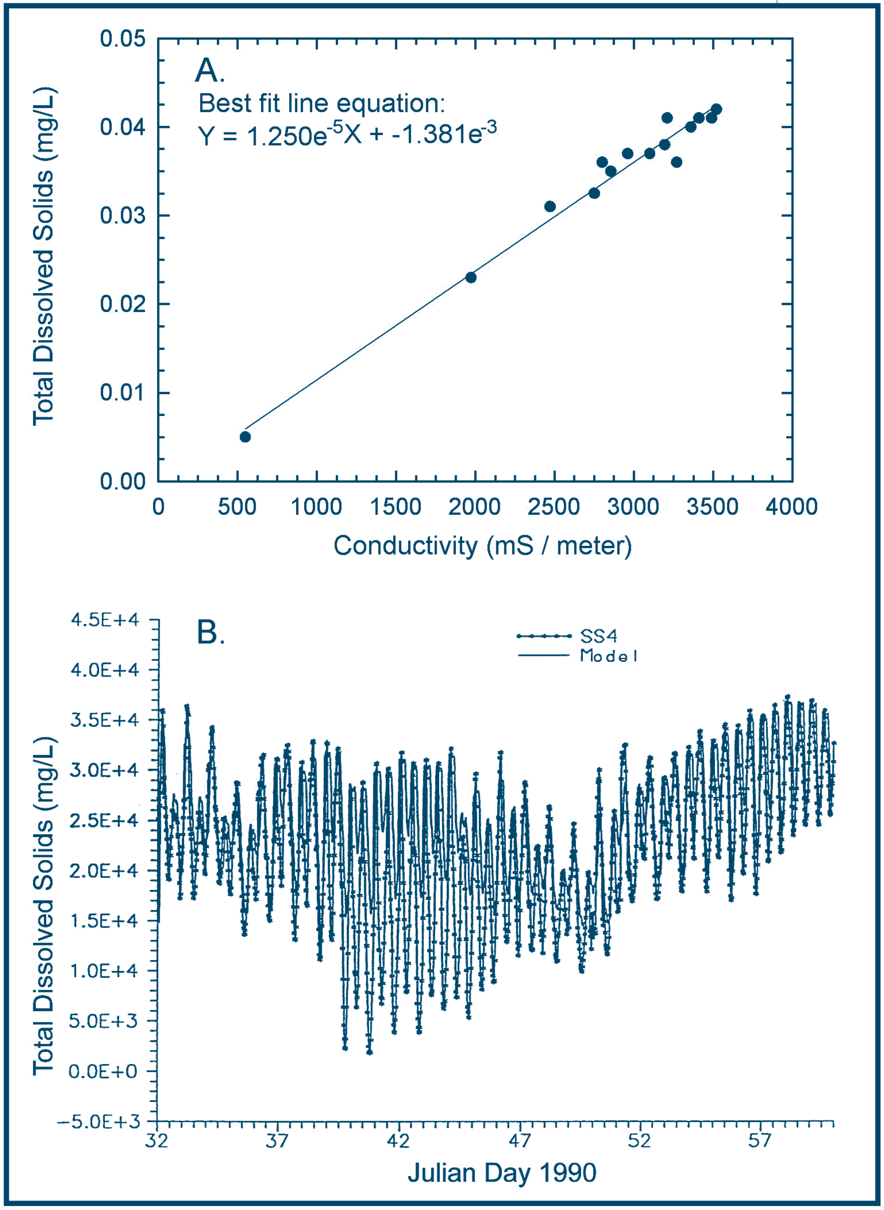


Figure 2.26. Tidal forcing of Total Dissolved Solids (TDS) in the South Slough estuary, OR. A) Relationship between TDS and water conductivity (16-17 Dec 1989); B) comparison of model predictions and SS4 measurements for tidal forcing of TDS in South Slough (adapted from Wells and Baird, 1990; and Juza 1995).

2.5.4 Water Quality within the South Slough Estuary

Tideflat areas within the South Slough estuary are conditionally approved for commercial oyster mariculture, although they are frequently closed to harvesting during and after significant rain events. Periodic harvest closures are required whenever estuarine water quality degrades and concentrations of pathogenic coliform bacteria increase in surface waters. State of Oregon/Department of Agriculture regulations prohibit shellfish harvests when total rainfall is 12.7 cm (5”) over 5 days, 6.3 cm (2.5”) over 3 days, or 3.8 cm (1.5”) over 24 hrs. These conditions, and any tidal exchange events where the difference between high and low tide exceeds 2.29 m (7.5 ft), prompt closure of the shellfish waters in South Slough for a period of 5 days.

Intestinal bacteria are commonly used as aquatic indicators of pathogenic contamination. These bacteria can enter the South Slough estuary from many point and non-point sources. Analysis of estuarine water samples collected during a single tidal event (Powell and Palmer, 2000) illustrate that the spatial pattern of coliform bacteria levels is complex along the South Slough estuarine gradient (Figure 2.27). Counts of total coliform bacteria exceeded 2000 colonies 100 ml^{-1} at several locations throughout the estuary (Hallmark dock, Hanson’s Landing, Joe Ney Slough, Colver Point, Brown’s Cove, Day Creek, Valino Island, Sengstacken arm mouth). Similarly, counts of *Escherichia coli* bacteria exhibited peaks in the northern region of the estuary (Charleston Marina, Hanson’s Landing, Joe Ney Slough), and in the vicinity of Day Creek, Valino Island, and Long Island Point. Peak numbers of fecal coliform bacteria also occurred at Joe Ney Slough and at slack tide near Valino Island and at the mouth of the Winchester arm. These data suggest that the primary sources of bacterial contamination are associated with docks and marinas, Joe Ney Slough, and a cluster of residential

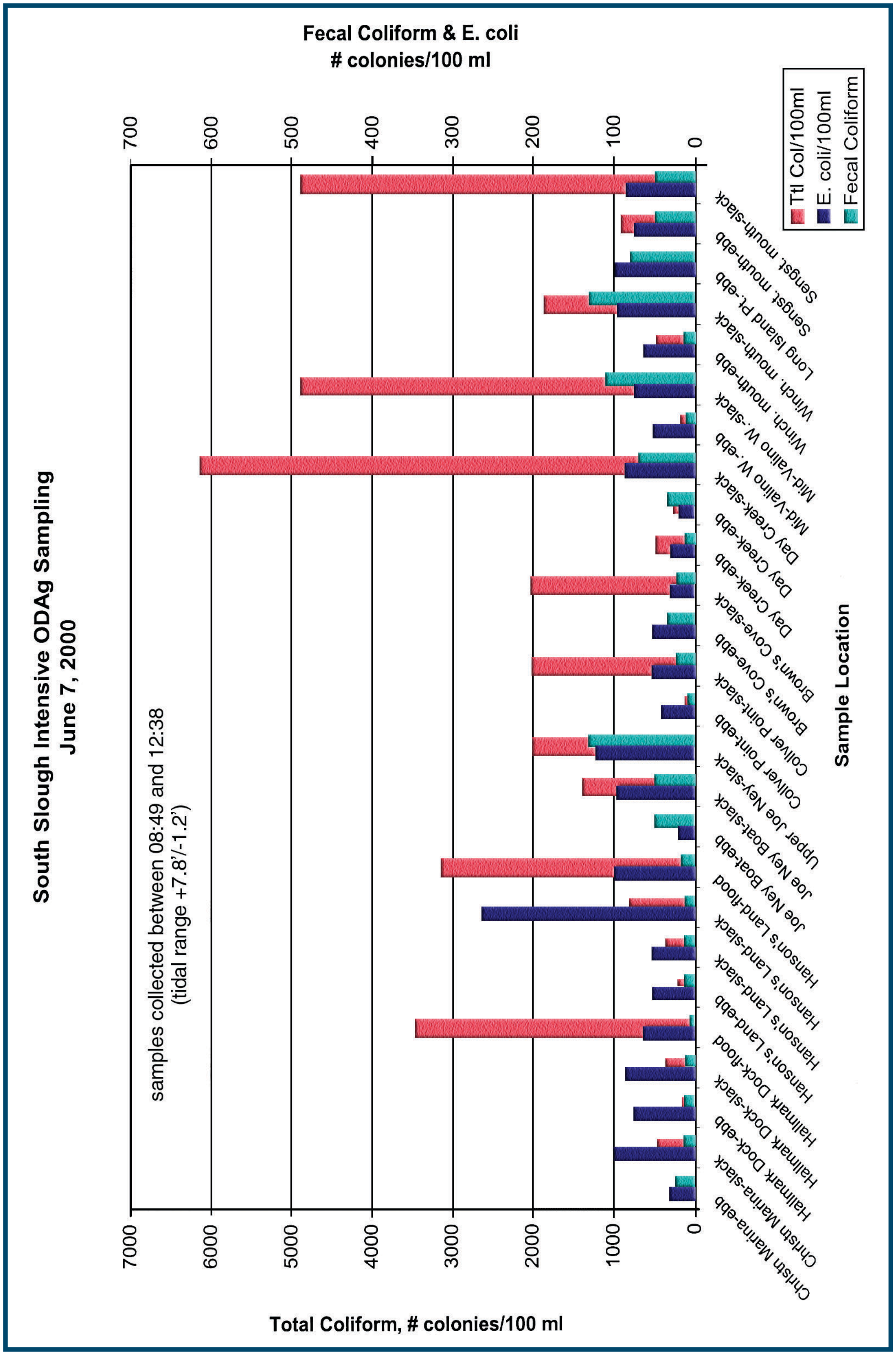


Figure 2.27. Spatial pattern of bacterial contamination along the South Slough estuarine gradient during a flood and ebb tidal cycle. Sampling and analysis conducted in cooperation between South Slough NERR and Oregon Department of Agriculture.

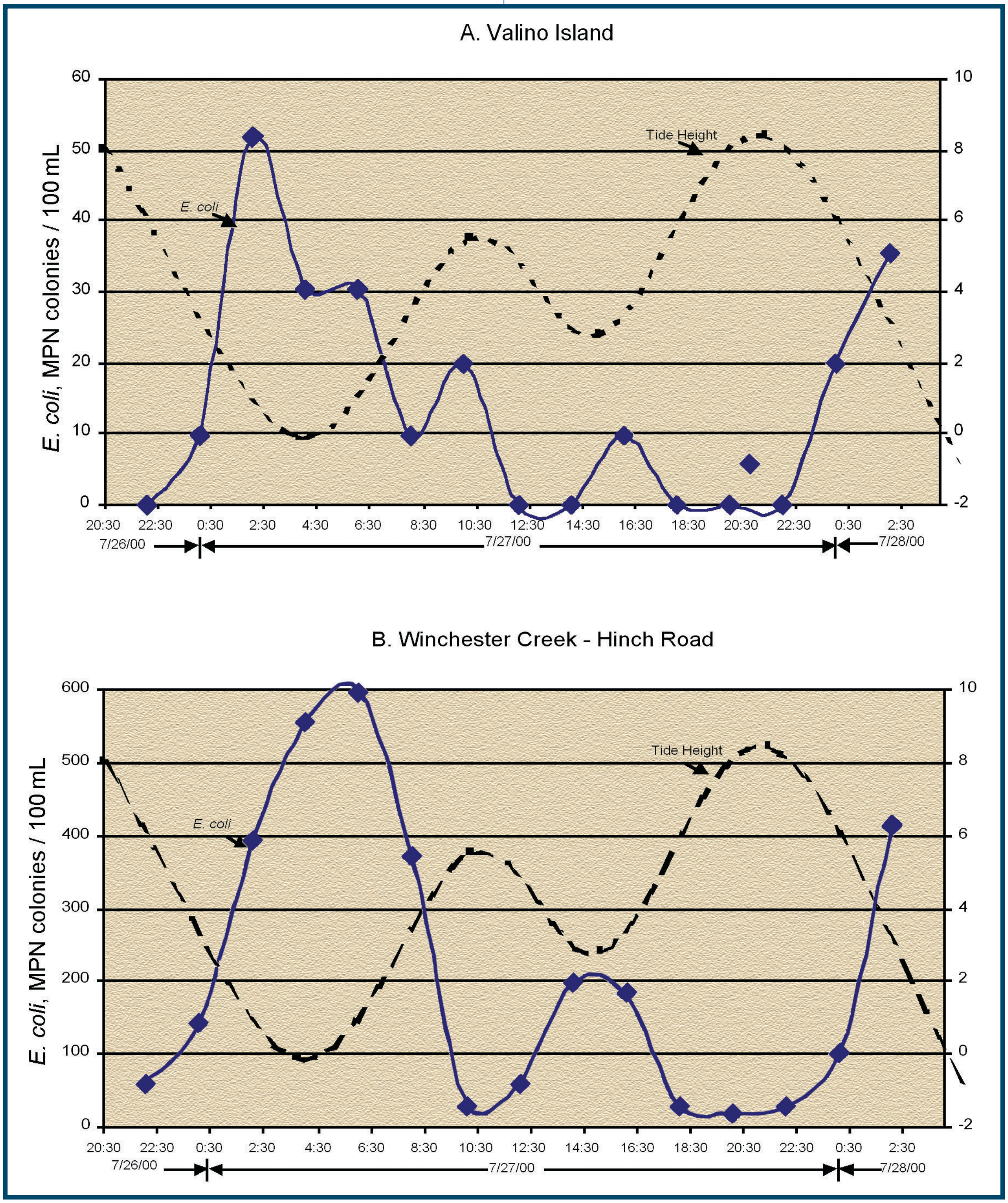


Figure 2.28. Time-series relationship between concentrations of *Escherichia coli* bacteria and tidal stage within the South Slough estuary, OR. A. Valino Island; B. Winchester Creek – Hinch Road Bridge. MPN indicates Most Probable Number of bacterial colonies (no. per 100 mL).

dwellings immediately north of the South Slough NERR. It is also possible that high bacteria counts near Valino Island are derived from upstream sources within the Sengstacken and Winchester arms of the estuary. Only a few livestock animals are held in pastures along creeks and tributaries upstream of the South Slough NERR (< 10 cattle and horses). Surveys of septic systems and grazing animals have not been completed along the shoreline of the estuary, and it is likely that some bacteria are derived from failed residential septic systems.

Other potential sources of bacterial contamination include beaver, deer, elk, harbor seals, seagulls and decaying marsh plants. Numerous beaver ponds exist along the shoreline of the South Slough, and it is possible that bacteria associated with beavers (and

Table 2.1. Tributyltin (TBT) levels in Pacific oyster (*Crassostrea gigas*) tissues collected from the South Slough estuary and North Bend, OR. Values indicated TBT levels (µg/kg wet weight; from Thomson *et al.*, 1990). * Analyses conducted by Moss Landing Marine Laboratory on composite samples using sodium hydroxide precipitation method; ** Analyses conducted by OR Department of Environmental Quality Laboratory on individual samples using Grignard reaction method.

Sample Site	June 87*	Oct 88**	Mar 89**	May 89**
St. H - Joe Ney Slough	88	26	33	13
St. I - lower Sough Slough	76			
St. J - Valino Is. west side	102		16	
St. K - mouth of Winchester arm	48		14	
St. L - mouth of Sengstacken arm	81		<3	15
St. Z - North Bend	189			22

decayed vegetation) may contribute to the high bacterial load. Seagulls have been shown to have a significant impact on bacterial contamination of estuarine water quality in Humboldt Bay, CA (Barnhart *et al.,* 1992) where they forage at a solid waste landfill and wastewater treatment plant and then congregate on mudflats at low tide to feed on herring eggs deposited on eelgrass blades. In the South Slough estuary, several hundred seagulls regularly feed on fish scraps scavenged from floating docks and wharves at seafood processing plants located at the estuary mouth. Additional bacterial contamination is undoubtedly contributed by vessels docked at the Charleston Marina where counts of bacterial colonies are occasionally very high. It is possible that some of the coliform bacterial contamination in the marine-dominated and mesohaline regions of the South Slough originate at the Charleston Marina and then enter the estuary on flood tides. Additional bacterial contaminants may be associated with a small herd of elk that forage in the riverine bottomlands, and from harbor seals that haul out on sandflats near Joe Ney Slough. Laboratory analyses are ongoing to identify the various sources of bacterial contamination. Polymerase Chain Reaction (PCR) tests with DNA primers are under development to identify the cluster of *Bacteroides-Provetella* bacteria that is diagnostic for ruminant fecal pollution, and to create a localized library of bacterial markers for beavers, harbor seals, and seagulls.

It is clear that substantial bacterial contamination is derived from terrestrial sources in the riverine tidal channels of the South Slough. Time-series sampling was conducted in July 2000 to quantify short-term variability in bacteria levels associated with the ebb and flood tidal cycle (Powell and Rumrill, 2001). Estuarine water samples were collected from the riverine region of Winchester Creek and near Valino Island at 2 hr intervals over a period of 30 hrs (Figure 2.28). Counts of *Escherichia coli* fluctuated inversely with the tides at both sites, and the greatest concentrations of bacteria (MPN>550 colonies 100 ml^{-1}) occurred during the lowest of the semi-diurnal tides at Winchester Creek. The time-series of bacterial concentrations followed a similar pattern at the Valino Island site although the peak counts of *E. coli* were much lower (MPN>50 colonies 100 ml^{-1}) due to dilution within the middle region of the South Slough. Other estuarine water quality standards including dissolved oxygen, pH, and nutrient loads are rarely exceeded in the tidal waters, although surface temperatures frequently become elevated above 20° C in the shallow tideflat channels.

2.5.5 Sediment Contaminants

Tributyltin (TBT) is an active ingredient of toxic antifouling paints applied to the hulls of many commercial and recreational vessels. TBT was used extensively in Oregon over a period of 20+ years, and TBT application was a routine maintenance activity within the Charleston shipyard located in the northern region of the South Slough estuary. Particulate TBT enters the estuarine environment and aquatic food chains by: (a) leaching from TBT-painted hulls and surfaces; and (b) shipyard maintenance such as scraping and sandblasting of antifouling paints. Concern about the harmful effects of TBT within the South Slough and potential adverse effects on human health from exposure to TBT prompted studies in the South Slough estuary and Coos Bay to document the distribution of TBT and its degradation products (monobutyltin, dibutyltin, and inorganic tin) in estuarine waters, sediments, and shellfish. Human health concerns also prompted statewide efforts to improve boatyard practices and legislation restricting the use of TBT paints on non-aluminum vessels less than 25 meters (82 ft) in length.

Commercial oysters (*Crassostrea gigas*) grown in the South Slough estuary exhibited abnormal growth patterns and chambered shells in 1987 (Thomson *et al.,* 1990). These abnormalities were similar to descriptions of growth problems reported for oysters cultivated in France and the United Kingdom in locations that were suspected of exposure to toxic levels of TBT. Estuarine water samples, sediments, and oyster tissues collected from the South Slough and Coos Bay were analyzed by the Oregon Department of Environmental Quality. TBT concentrations were detected in the estuarine waters at concentrations of up to 14 ng L^{-1} (or parts per trillion (ppt)) in 1987. TBT concentrations in oyster tissues ranged from 50 to 102 ug kg^{-1} wet weight (or parts per billion ppb) within the South Slough estuary and 189 ug kg^{-1} wet weight at a sample site in Coos Bay near the city of North Bend (Table 2.1). Subsequent analysis of oyster tissues in 1988-89 found substantially lower TBT levels (< 3 to 33 ug kg^{-1} wet weight). Improper shipyard practices were believed to be a major contributor of TBT to the South Slough estuary.

Elevated levels of hazardous waste contamination of the shoreline sediments warranted consideration of the Charleston shipyard as a potential U.S. Environmental Protection Agency Superfund cleanup site in 1998. Instead, voluntary cleanup of the shipyard was completed by the Oregon International Port of Coos Bay in 2001, including burial of contaminated sediments in an underground cell and installation of a containment, collection, and filtration system. Cleanup of the Charleston shipyard is considered a success, and new best-management practices are in place to ensure the shoreline operations no longer pose an ecological threat to the South Slough estuary.

2.6 Accretion of Sediments in the South Slough Estuary

The South Slough tidal basin is an area of relatively rapid sediment deposition. Sediments are generally transported seaward and deposition occurs in regions where the retention time of particles is high (Baker, 1978). Thom (1992) provided estimates of sediment accretion at 0.2 to 0.5 cm yr^{-1} measured over the last 40 yrs (by ^{137}Cs counts in sediment cores) for Pacific northwest estuaries, and SET-Table measurements varied between 0.5 and 3 cm yr^{-1} for low intertidal marshes within the South Slough NERR. These are comparable to the estimates of 0.5 to 1.7 cm yr^{-1} reported earlier by Jefferson (1975) for the low silty Oregon salt marshes. Accretion of sediments is not uniform among the salt marshes and tideflat habitats because sediment loads vary from one site to another and current velocities can vary due to friction associated with plant densities, water volume, and the area available for tidal spreading and inundation. Sediment deposition is usually greatest along the banks of channels where current velocities decrease rapidly. Sediment deposition is also more strongly related to episodic storm events (Baker, 1978), rather than the daily cycle of tidal inundation or cumulative bedload transport.

2.7 Watershed Land Use and Ownership

The South Slough watershed is a mixed-use drainage basin that contains parcels zoned for municipal development, shoreline industry, private residential uses, farmland, private commercial and public timber production, and for the South Slough National Estuarine Research Reserve (see Figure 1.34). As a mixed-use basin, the South Slough watershed provides a representative example of a Pacific northwest coastal ecosystem that integrates functional processes within upland forests and commercial timberlands, coastal streams and riparian areas, estuarine tidelands, nearshore marine regions, and varied municipal, rural, and industrial areas. These distinct landscape elements form a series of linked land-margin habitats that are particularly well-suited to interdisciplinary research aimed at understanding large-scale patterns and processes that contribute to a healthy coastal ecosystem.

Municipal development and shoreline industrial activities are concentrated at the mouth of the South Slough estuary, immediately north and south of the

Charleston bridge (see Figure 1.32). Historic salt marshes located at the mouth of the estuary (near its confluence with the Coos estuary) have been filled with sandy dredged materials to provide flatlands for the township of Charleston, U.S. Coast Guard facilities, an academic marine institute, docks and marinas, port and harbor landing areas, recreational parking lots, seafood processing plants, shipyards, and other shoreline developments. Only a few acres of fringing marsh remain in the northern region of the South Slough estuary. Submerged and submersible lands that make up the 783 ha. estuarine tidal basin are owned largely by the State of Oregon Department of State Lands, although a few parcels of tidelands are under private ownership.

Private residential parcels are limited primarily to the northern region of the South Slough watershed, and they extend to the shoreline along the north-western region near Metcalf marsh and Collver Point, within Joe Ney Slough, and along the shoreline of Crown Point. Joe Ney Slough is a subsidiary tidal inlet that merges with South Slough near the Charleston bridge. The lower region of Joe Ney Slough is used for commercial oyster mariculture, and the upper waters are dammed for municipal water storage. Light residential use extends into the northeast region of the watershed. A municipal landfill is located in the eastern region of the watershed at the headwaters of Day Creek. The landfill is operated primarily as a disposal facility for construction debris. The steep west ridge of the South Slough watershed provides the primary roadway for vehicular travel (Seven Devils Road) and access routes for residential development. These are primarily private homes and small woodlots with occasional grazing pastures for horses.

The South Slough NERR encompasses *ca.* 4,770 acres of tidelands and upland forest habitats, and makes up about 24% of the entire South Slough watershed (see Figure 1.34). Within the South Slough NERR, the estuarine tidal basin is composed of about 550 acres of intertidal land consisting of mudflats, eelgrass beds, and tidal marshes, and approximately 40 acres of subtidal channels. Tidal habitats within the South Slough NERR are bounded on their upstream sides by a series of freshwater streams and riparian corridors that transgress into upland forest habitats including maturing stands of conifers and deciduous trees (>70 years old), brushy hillsides, and recovering clearcuts.

The southern region of the South Slough watershed is primarily owned and managed by Coos County and private companies for timber production (see Figure 1.32). Like many other coastal watershed landscapes located along the southern Oregon coast, the upland forest communities within the South Slough watershed are strongly influenced by commercial plantings of Douglas-fir (*Psudotsuga menziesii*). Significant stands of western hemlock (*Tsuga heteroplylla*) and Port-Orford-cedar (*Chamaecyparis lawsoniana*) occur within the watershed, along with associated stands of Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), red alder (*Alnus rubra*), and big leaf maple (*Acer macrophyllum*). Portions of the South Slough watershed are also used for recreational fishing, hunting, hiking, horseback riding, motorcycling, bicycling, and other recreational pursuits. A few cattle continue to graze in the lowlands adjacent to Winchester Creek immediately south of the administrative boundaries of the South Slough NERR.

Chapter 3

Estuarine Habitats and Communities

3.1 Habitat Classification within the South Slough Estuary

The South Slough estuary contains several different types of intertidal and subtidal habitats that are occupied by a wide diversity of biotic assemblages. The spatial mosaic of habitats results from the interaction of several physical variables, including location along the estuarine gradient, substratum and energy regime, intertidal elevation and topography, and the extent of tidal influence. The spatial distribution of habitats and the composition of biotic communities is also dependent on several biotic variables, such as the physiological tolerances of the organisms to desiccation, thermal heating, exposure to fresh and saline water, episodic burial by sediments, predation, competition, recruitment, and a suite of other biotic stressors.

Detailed habitat classification systems have been developed specifically for Pacific northwest estuaries by Bottom *et al.,* (1979), Dethier (1990), and Simenstad *et al.,* (1991). These estuarine classification systems are regional derivatives of the U.S. Fish and Wildlife Service – Wetland Classification Scheme (Cowardin *et al.*, 1979) and they incorporate the hierarchical breakdown of estuarine subsystems based on tidal regime, substratum class, exposure to wave energy, representative fish and wildlife assemblages, and other modifiers (see Figure 1.17). A new habitat classification scheme has recently been developed for marine and estuarine ecosystems that adds additional hierarchical groupings (eco-units) that are logically linked to the underlying mechanisms that structure the ecosystem and biotic communities (Allee *et al.,* 2000).

The Oregon Estuarine Habitat Classification Scheme (Bottom *et al.,* 1979; Cortright *et al.,* 1987) can be modified and adapted to the South Slough estuary to recognize four distinct geomorphic zones and eight major types of estuarine habitats (Figure 3.1). First, the Marine - Estuarine Interface Zone is located immediately outside the mouth of the South Slough estuary and includes the lowermost region of the Coos estuary and the nearshore region immediately outside the jetties. This interface zone is characterized by marine waters with a salinity range of 33 to 25 psu (practical salinity units). During rainy periods when river discharge is high (*i.e.* February 1996) the Marine - Estuarine Interface Zone can be expansive and extend outside the jetties in the form of an estuarine plume that extends into the sea as far south as Gregory Point and northward along the shoreline of North Spit. During the dry season the Marine - Estuarine Interface Zone is relatively small and confined to the lower region of Coos Bay where mixing occurs with the daily ebb and flood of the tides (Juza, 1995; Roegner and Shanks, 2001). Second, the Marine Dominated - Lower Zone is located immediately inside the mouth of the estuary (Charleston / Barview Wayside) southward to Valino Island. The Marine-Dominated zone is characterized by high variability in salinity (30 to 18 psu). Further up the estuary, the third geomorphic zone (Middle Estuary – Mesohaline Zone) is located from the tip of the Long Island Peninsula southward to the Kunz marsh (Winchester Arm) and to the confluence of Talbot and John B. Creeks (Sengstacken Arm). The mixing zone is characterized by waters with a salinity range of 28 to 5 psu. Fourth, the Upper Estuary - Riverine Zone is located primarily along Winchester, Elliott, Talbot, and John B. Creeks to the head of tide. Salinity typically ranges from 22 to 0 psu and is characterized by seasonal and episodic inputs of freshwater.

Eight major estuarine habitats occur within the South Slough estuary (Figure 3.1). These primary habitat types and their associated assemblages of organisms are summarized below and discussed in the sections that follow:

1. ***Open Water and Estuarine Water Column***
    - Phytoplankton and Protist Communities: Bacteria, Flagellates, Diatoms
    - Neustonic Layer: Decapod megalopae
    - Zooplankton Communities: Copepods, Decapod zoeae, Hydromedusae
    - Midwater Fish: Herring, Perch, Anchovy, Smelt, Searun Cutthroat Trout
2. ***Tidal Channels and Drainage Creeks***
    - Plankton Communities: Diatoms, Copepods, Hydromedusae
    - Oysters, Crabs & Shrimp: *Ostrea, Cancer, Heptacarpus, Crangon*
    - Resident Fish: Perch, Sculpin, Stickleback
    - Anadromous Fish: Cutthroat trout, Chinook, Coho salmon
3. ***Submerged Aquatic Vegetation***
    - Eelgrass: *Zostera marina, Zostera japonica*
    - Macroalgae: *Ulva, Enteromorpha, Chaetomorpha*
4. ***Sandflats and Mudflats***
    - Infaunal Invertebrates: Polychaetes, Amphipods, Clams
5. ***Bioturbated / Burrowing Shrimp Beds***
    - Ghost shrimp: *Neotrypaea californiensis*
    - Mud shrimp: *Upogebia pugettensis*
6. ***Salt Marshes***
    - Emergent Plants: *Deschampsia, Triglochin, Carex, Salicornia*
7. ***Bedrock, Gravel, Cobble and Miscellaneous Hard Substrata***
    - Sessile Invertebrates: Barnacles, Mussels, Boring clams
    - Motile Invertebrates: Shore crabs, Porcelain crabs
8. ***Anthropogenic / Constructed Habitats***
    - Hardened Structures, Rip-rap & Jetties: Barnacles, Seaweed
    - Docks, Marinas & Pilings: Barnacles, Seaweed, Isopods, Seastars
    - Commercial Oyster Reefs: *Crassostrea gigas*

3.2 Open Water and the Estuarine Water Column

Direct connection of the South Slough to the marine waters of lower Coos Bay and the nearshore Pacific Ocean allows the open waters of the estuary to experience the full gradient from marine to freshwater influence. Open water habitats and the estuarine water column include that portion of the subtidal regime that is not directly associated with the bottom. The open water habitat includes the neustonic layer at the surface but not the benthic boundary layer immediately associated with the bottom.

3.2.1 Estuarine Phytoplankton and Protist Communities

Estuarine phytoplankton are a major source of autotrophic primary production in the open water habitats of the South Slough. Assemblages of estuarine phytoplankton are influenced seasonally and spatially by variation in ocean forcing, nutrient availability, solar energy, and riverine inputs. The typical successional pattern in Pacific northwest estuaries begins with low densities of phytoplankton in late fall and winter (due to reduced light and high turbidity), followed by a bloom of small diatoms in late winter / early spring. The diatom bloom usually terminates in late spring when nitrogen sources are depleted, and phytoplankton densities remain low in the summer months when nutrient availability is low and grazing pressure is high (Karentz and McIntire, 1977; Pequegnat and Butler, 1982; Nybakken, 1993).

The seasonal cycle of size-fractionated phytoplankton (chlorophyll concentrations in < 5 µm and > 5 µm cells) was measured within the surface waters of the South Slough estuary near Valino Island in 1999-2000 (Cowlishaw, 2001). Total chlorophyll concentrations were predictably low in the late fall and winter (< 1 ug l^{-1}) and began to rise in April-May (Figure 3.2). Peak chlorophyll concentrations (3-6 ug l^{-1}), however, remained high from June-August, followed by a rapid decline in September-October. Chlorophyll concentrations contributed by the small ultraplankton size fraction (< 5 µm dia) exhibited a similar seasonal cycle and added about 42% of the total chlorophyll. Relatively high concentrations of chlorophyll measured throughout the summer suggest that nutrient availability in the marine

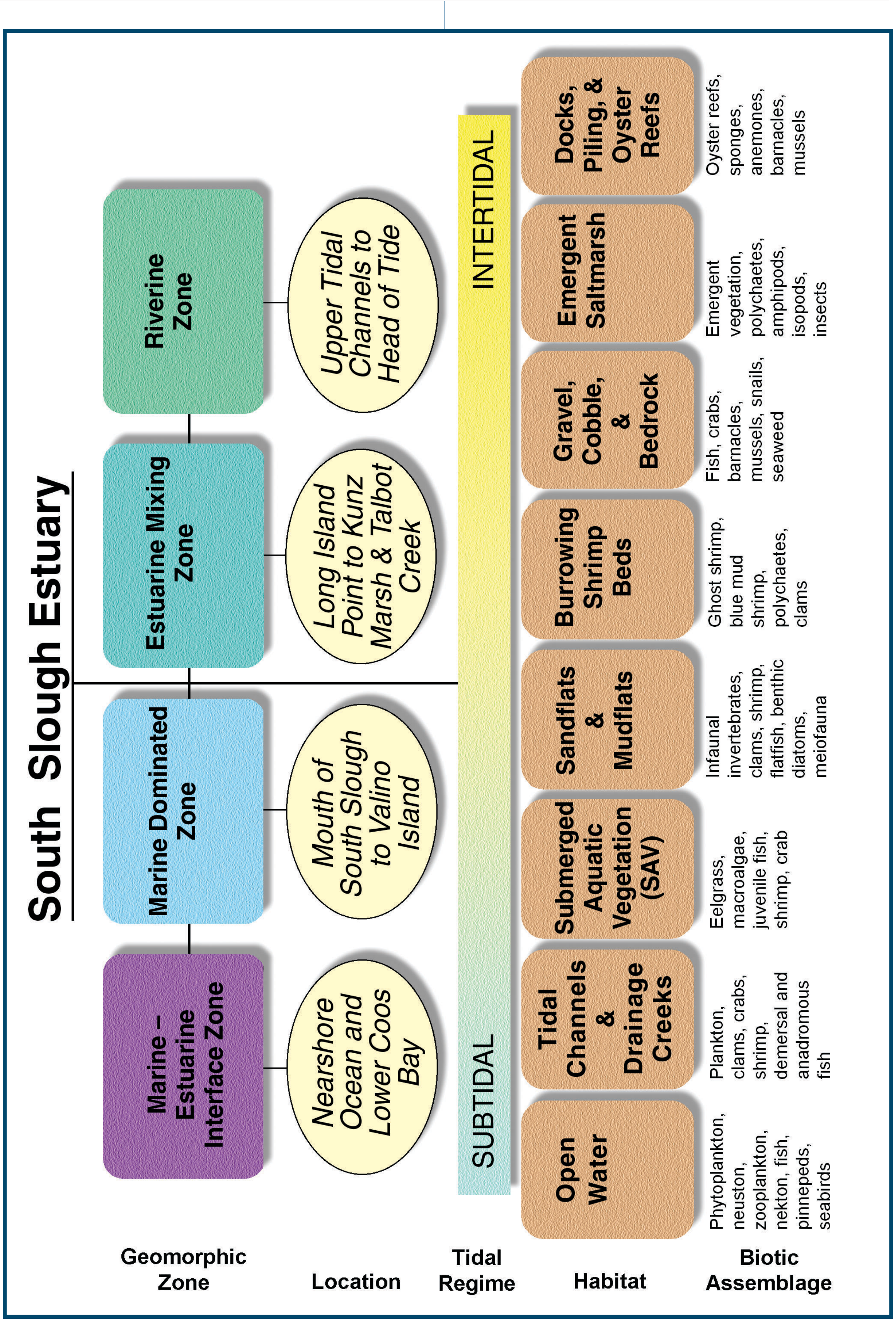


Figure 3.1. Geomorphic zones and habitat classification for the South Slough estuary, OR

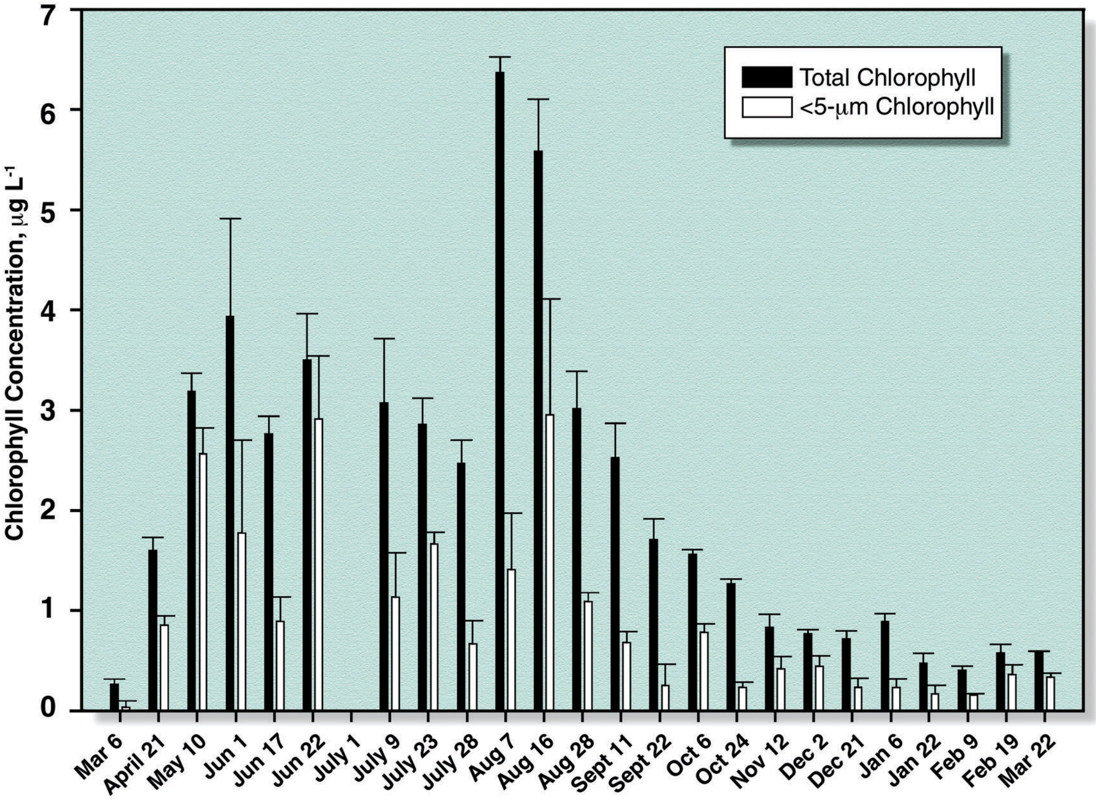


Figure 3.2. Time-series of chlorophyll concentrations within the tidal channel near Valino Island, South Slough NERR (1999-2000). Values indicate total and size-fractionated (<5mm) chlorophyll (from Cowlishaw, 2001).

dominated region of the South Slough estuary may be pulsed and tightly linked to seasonal upwelling of the nearshore ocean in the summer months.

Composition and distribution of phytoplankton communities (diatoms, dinoflagellates, and ultraplankton < 5 µm dia) varies seasonally along the South Slough estuarine gradient. The pennate diatom *Pseudo-nitzschia australis* occurs in the marine waters of Coos Bay and in the northern region of the South Slough (Figure 3.3). These diatoms are known to produce toxic domoic acid in association with marine bacteria (Watson, 1994). Strong seasonal patterns occur within the estuarine water column for many groups including cyanobacteria, chlorophyll-dominant eukaryotes, cryptomonads, centric and pennate diatoms, autotrophic and heterotrophic dinoflagellates (*i.e., Gyrodinium* sp.), and ciliates.

Different members of the phytoplankton assemblage exhibited contrasting distribution and abundance patterns along the South Slough estuarine gradient. For example, cyanobacteria (*i.e., Synechococcus* sp.) and the small (< 3 µm) chlorophyll-dominant eukaryotes were numerically the most abundant members of the phytoplankton community (Hughes, 1997). Cyanobacteria were most abundant in the marine waters near the mouth of the estuary, intermediate within the middle estuarine mixing zone, and least abundant in the riverine region.

Synechococcus sp. is a small (*ca.* 1 µm dia) photosynthetic cyanobacterium that is rich in phycoerythrin. These cells have been observed in high concentra-

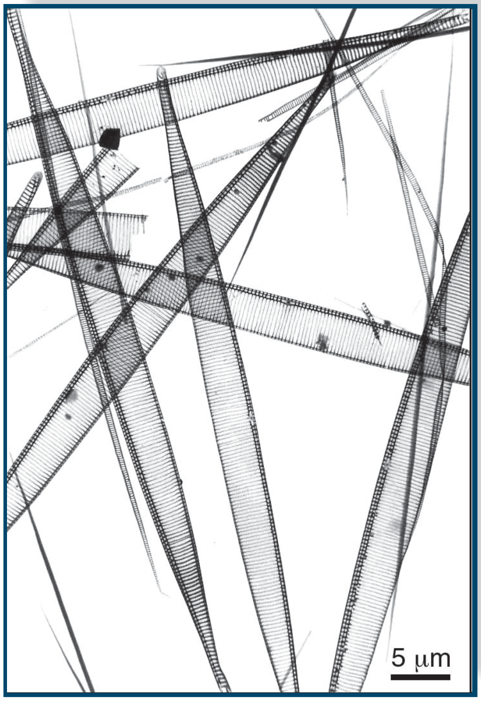


Figure 3.3. Pennate diatoms (*Pseudo-nitzschia australis*): Transmission electron micrograph of acid-cleaned diatom frustules (approximate cell volume 3067mm^3). TEM by S. Watson, 1994.

tions (10^5 – 10^8 cells per liter) throughout the world's oceans and coastal waters (Glover *et al.,* 1985; Murphy and Haugen, 1985), and they can be considered as a biotic indicator of phytoplankton that originate in marine waters.

Centric diatoms exhibited peak abundance in late spring in the marine-dominated region of the South Slough, while pennate diatoms were most abundant in early spring in the mid region of the estuary (Hughes, 1997; Figure 3.4). *Coscinodiscus* sp., *Melosira* spp., and *Skeletonema* spp. are common centric diatoms in the water column of the South Slough estuary, and the chain-forming diatoms *Thalassiosira* sp. and *Chaetoceros* spp. are also locally abundant. In contrast, the small chl-dominant eukaryotes were most abundant in the middle mixing zone, while the cryptomonads, autotrophic dinoflagellates, and other autotrophs became increasingly more abundant farther up the estuary in the riverine region. Small phototrophs, dinoflagellates, large autotrophic phytoplankters, and heterotrophic protists exhibited two annual peaks in the South Slough with a fall bloom that was equal or greater than the spring bloom (Hughes, 1997).

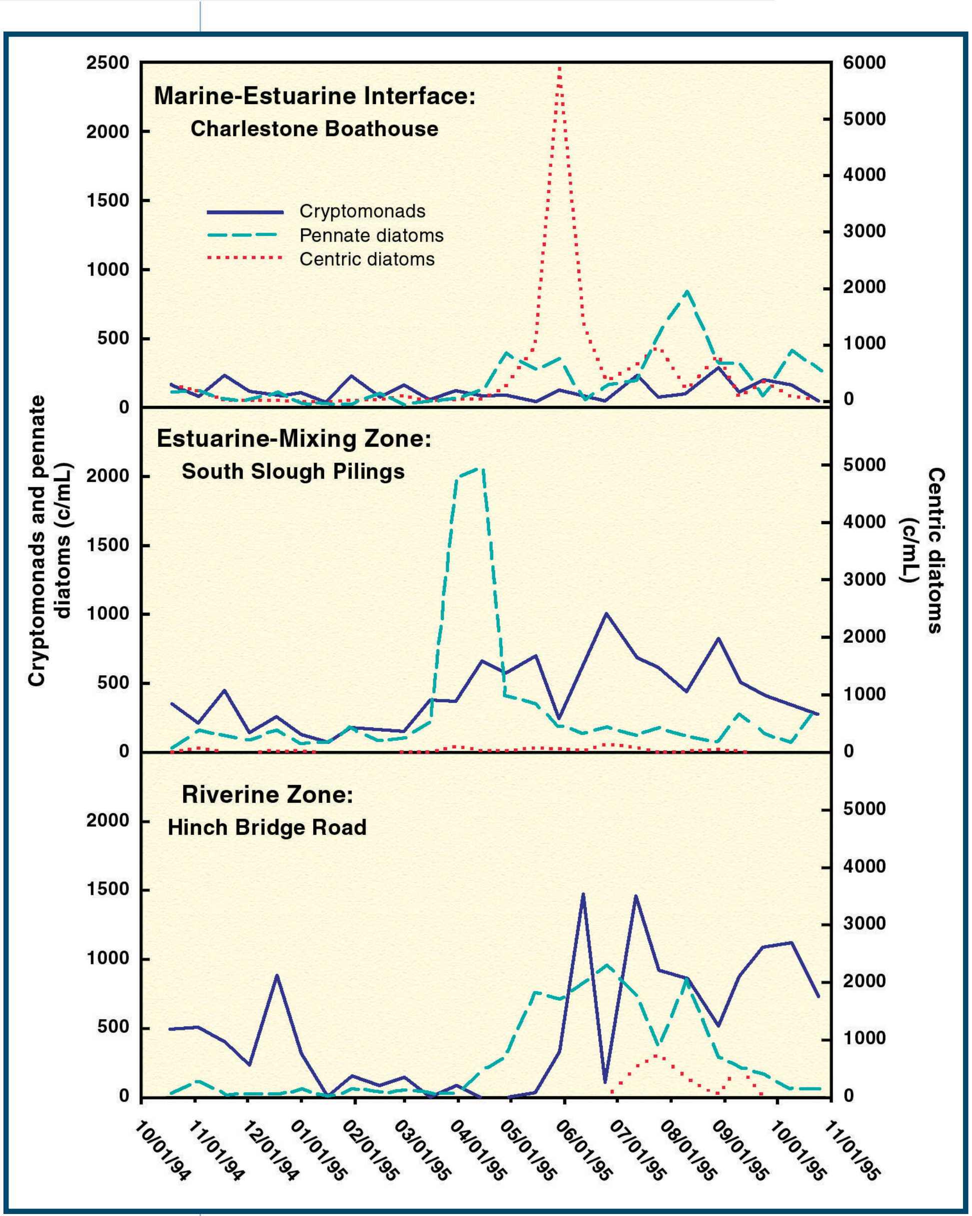


Figure 3.4. Time-series of phytoplankton abundance at three sites along the South Slough estuarine gradient (adapted from Hughes, 1997).

Water temperature and salinity are highly seasonal water parameters, particularly in the riverine region of the South Slough. Solar radiation (photoperiod and total incident Photosynthetically Active Radiation / PAR) and nutrient availability are of primary importance in determining daily rates of phytoplankton cell division (Hughes, 1997). Phytoplankton cells that occur in the shallow tideflat regions of the South Slough may encounter warmer temperatures and greater PAR to allow for rapid growth. Conversely, growth rates may be slower for phytoplankton in the deeper, more northern region of the estuary where they are mixed beyond typical Secchi depths (1.5-2 m). Persistence of the distinct marine, estuarine, and riverine phytoplankton assemblages within different regions of the South Slough estuary will depend on the extent of tidal circulation and mixing of the estuarine water masses over short-term and longer time scales. A significant fraction of the particulate organic material produced within the South Slough is probably altered or metabolized by bacteria before it is carried out to the Coos estuary and the nearshore ocean. Mixing of saline and freshwater within the middle estuarine turbidity maxima (ETM) region of the South Slough serves to trap water-borne particles and lengthen the residence time for organic material, increasing the availability of organic material to estuarine bacteria and the estuarine food web.

Cowlishaw (2001) also enumerated the annual cycles for heterotrophic nanoflagellates (flagellates < 20 µm in size) and oligotrich ciliates. The seasonal abundance of ciliates was highly correlated with the abundance of small ultraplankton (< 5 µm) in the estuarine water column, but not with the abundance of the larger phytoplankton cells. Ciliates contributed an average of 32% (monthly range 6-75%) of the available carbon in the South Slough water column over the period from June 1999 to March 2000. Accordingly, the seasonal abundance of heterotrophic nanoflagellates was significantly correlated with the numbers of small ciliates (< 20 um). These seasonal cycles indicate that primary production in the estuarine water column is dominated by small phytoplankton cells, and that important trophic relationships most likely exist between the nanoflagellates, ciliates, and ultraplankton in the South Slough (Cowlishaw, 2001).

Small phytoplankton cells (< 5 µm dia) contribute the greatest proportion of primary production within the water column of the South Slough estuary (Cowlishaw, 2001). Herbivorous copepods, however, are unable to feed effectively on cells of this size. Conversely, microzooplankton (*i.e.,* ciliates and flagellate protozoans < 200 µm) are efficient consumers of ultraphytoplankton in the tidal waters of the South Slough. Similarly, Crump and Baross (1996) found that nanoflagellates, small oligotrich ciliates, and rotifers were the primary consumers of bacteria and small phytoplankton in the estuarine turbidity maxima region of the Columbia River estuary, OR. Experimental evidence of predator-prey interactions in the South Slough collected by Cowlishaw (2001) suggests a much larger role for microzooplankton in the dynamics of coastal and estuarine food webs. Microzooplankton serve as the principal consumers of marine primary production in a complex trophic cascade that includes direct and indirect links between herbivorous copepods, protozoans, flagellates, diatoms, and small ultraplankton. Heuristic models that seek to elucidate pathways for energy flow in Pacific northwest estuaries should incorporate the trophic links between ultraphytoplankton, protozoans, and flagellates as an important mechanism for energy transfer in coastal waters.

3.2.2 Neustonic Layer

The neuston layer of the South Slough estuary includes microscopic and macroscopic members of bacteria, phytoplankton, protistan, and zooplankton communities that inhabit the surface and subsurface (0 to 0.5 m depth) waters of the open tidal channels and inlets. Diverse communities of phytoplankton and zooplankton occur in neuston net tows from the marine-dominated region of the South Slough tidal channel (Puls, 2001). Chaetognaths, copepods, barnacle nauplii and cyprids, zoea larvae from several decapod crustaceans (*Hemigrapsus oregonensis, Lophopanopeus bellus, Pachygrapsus crassipes, Pinnixa* spp., *Pagurus* spp., several porcelain crabs, *Neotrypaea californiensis, Emerita analoga*), hydromedusae (*Clytia gregaria, Aequorea* spp.), ctenophores (*Pleurobrachia bachei*) and fish larvae are seasonally abundant in the neuston (Figure 3.5). Surface net tows also frequently include floating insects, dislodged eelgrass blades (*Zostera marina*) and drift algae (primarily *Ulva* spp. and *Fucus* sp.). Temporary inhabitants of the neuston, particularly the meroplanktonic embryos and larvae of fish and benthic invertebrates, utilize the surface layer during a portion of their planktonic dispersal period.

Surface temperatures typically vary little from sub-surface temperatures throughout the well mixed estuarine water column. Consequently, neustonic assemblages are ephemeral and may be concentrated for brief periods in the surface layer by local winds, tidal convergences, and other short-term hydrological processes rather than persist in water masses separated by a thermocline or halocline. Turbulent mixing of the water column often results in vertical homogenization of the largely passive neuston communities, although a distinct organically-enriched surface microlayer of buoyant detritus, bacteria, planktonic organisms and fine sediments can develop during extended periods of calm weather. Coarse sediment particles and organic materials sometimes adhere to the air/water interface by surface tension and they are transported over unknown distances by the tidal currents. In other cases, zooplankton (particularly decapod crustacean larvae) can exhibit strongly photopositive swimming behaviors to ensure they consistently occur in the estuarine surface waters.

In late spring and summer, the surface neuston community sometimes includes numerous gelatinous hydromedusae, ctenophores, and battered specimens of the floating colonial hydroid *Velella velella* that have been blown to shore and into the estuary from the open ocean on westerly winds. These macroneuston undoubtedly contribute in some fashion to the food web that links the sea surface of the outer coast with the subsurface organisms that inhabit the estuarine tidal channels. Details of these direct and indirect trophic relationships, however, remain unclear.

3.2.3 Zooplankton Communities

Like other estuaries and protected embayments in the Pacific northwest, the South Slough estuary harbors a rich diversity of zooplankton. Composition of the estuarine zooplankton assemblages varies substantially on a temporal (tidal, diel, seasonal) basis and with the location and origin of the water mass. The permanent (holoplankton) and temporary (meroplankton) members of the zooplankton community swim weakly within the estuarine water column, and their distribution is determined largely by tidal advection into and out of the South Slough (Puls, 2001). In some cases, however, species may exhibit vertical migration patterns as a behavioral mechanism that serves to retain larvae within the estuary and resist advection into the nearshore ocean.

3.2.3.a Holoplanktonic and Meroplanktonic Invertebrates

Holoplanktonic invertebrates that commonly occur within the South Slough estuary include the calanoid copepods (*Acartia tonsa, A. californiensis, A. clausi, Oithona* sp., *Pseudocalanus* sp.), hyperiid amphipods, ostracods, cladocerans, larvaceans (*Oikopleura* spp.), and ctenophores (*Pleurobrachia bachei*). Hydromedusae such as *Polyorchis pennicillatus, Aequorea aequorea, Clytia gregaria, Obelia* spp., and *Gonionemus vertens* are common in the marine-dominated tidal waters of the South Slough (Figure 3.5). Damaged specimens of the moon jelly *Aurelia aurita* and other jellyfishes (*Chrysaora* spp. and *Pelagia colorata*) are sometimes swept into the South Slough on flood tides.

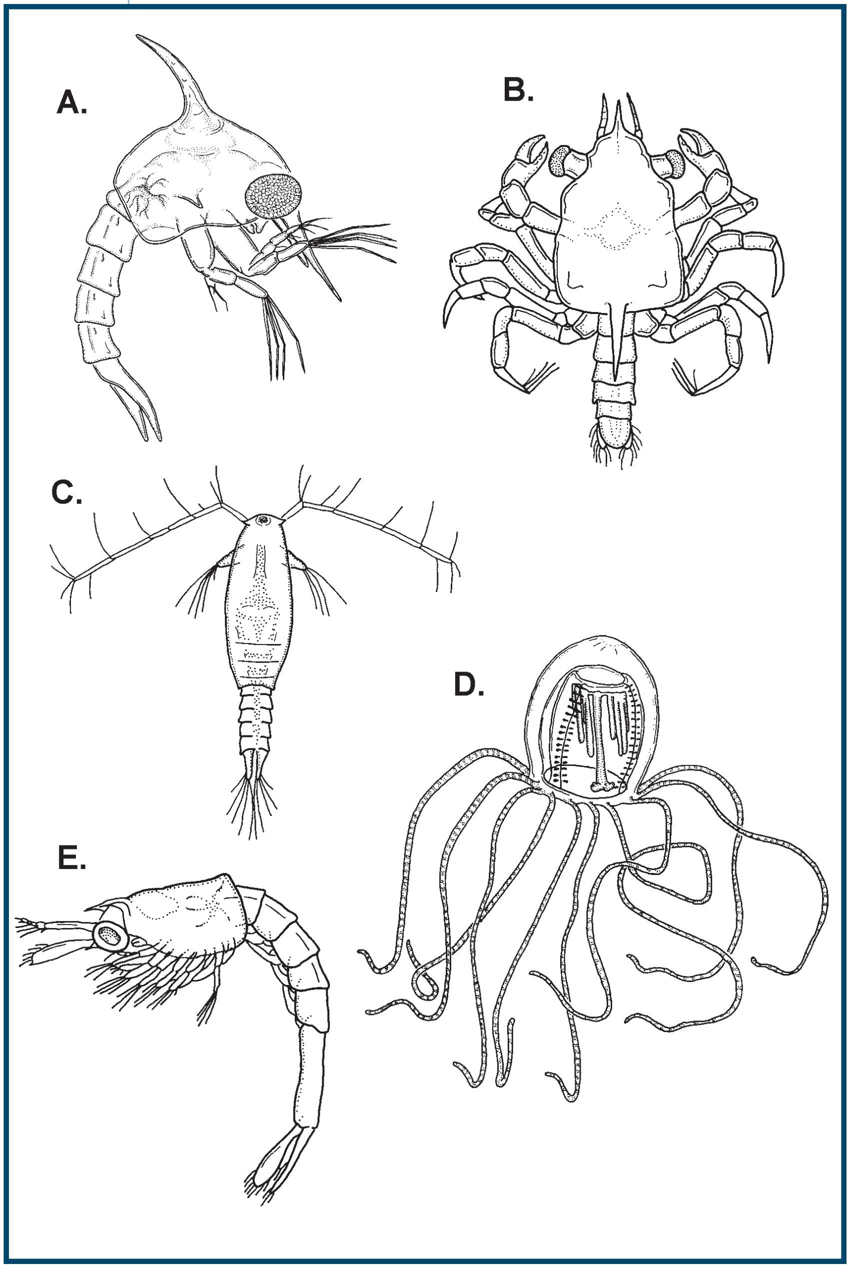


Figure 3.5. Zooplanktonic organisms from the South Slough estuary. A. Decapod zoea larva: *Pugettia*; B. Decapod megalops larva: *Cancer*; C. Calanoid copepod: *Acartia*; D. Hydromedusa: *Polyorchis*; E. Decapod zoea larva: *Upogebia*. Illustration by S. Rumrill.

Meroplanktonic larvae from benthic marine and estuarine invertebrates are also common members of zooplankton assemblages within the open waters of the South Slough estuary (Puls, 2001). These include the nauplius and cyprid larval stages from several barnacles (*Balanus glandula, B. crenatus, B. nubilus, B. improvisus, Semibalanus cariosus, Chthamalus dalli*, and *Pollicipes polymerus*) as well as the trochophore and metatrochophore larval stages from several polychaetes (*i.e., Cirriformia, Glycinde, Nephtys* spp., *Polydora* spp.). Early stage zoea larvae

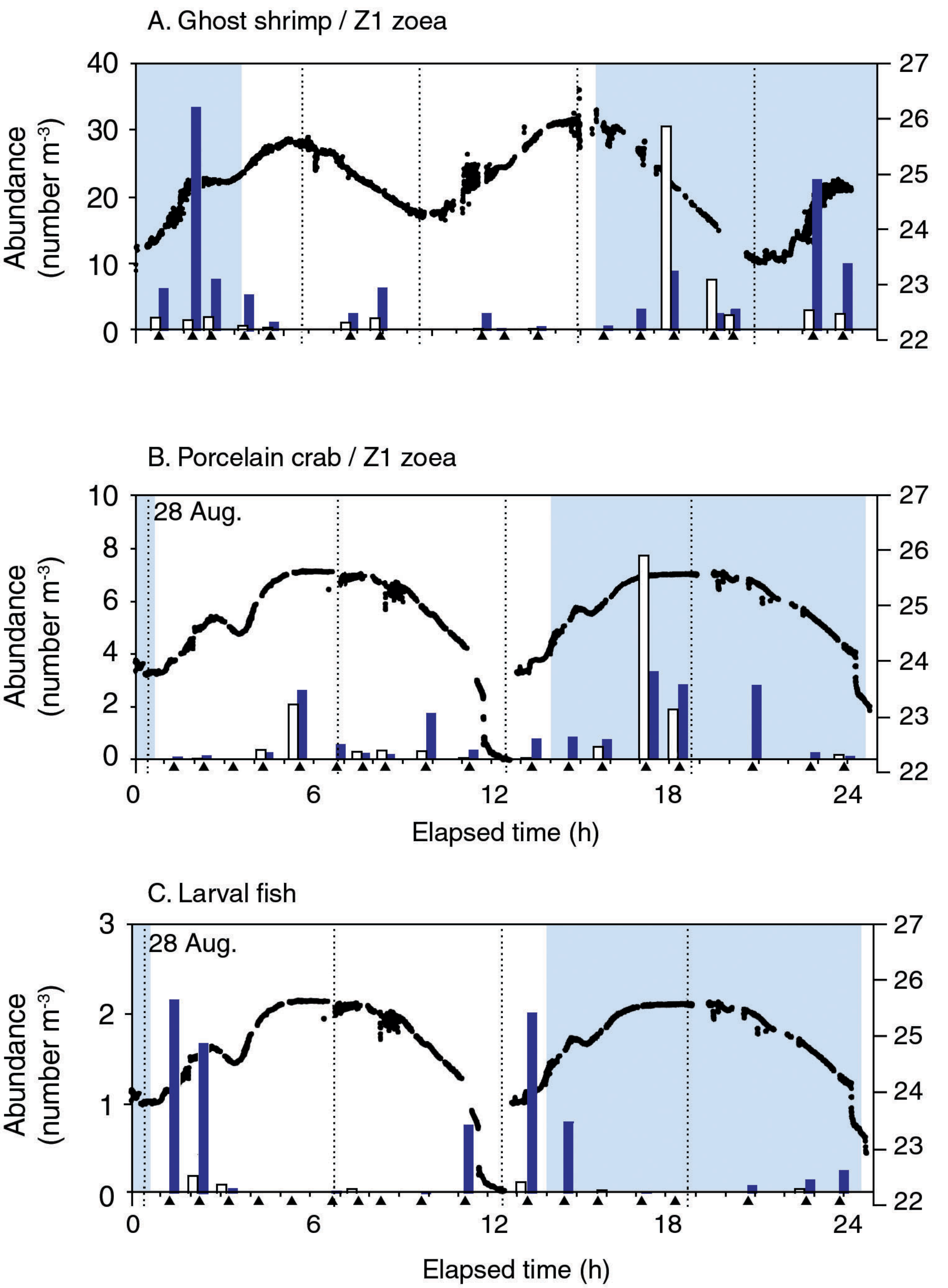


Figure 3.6. Time-series of the abundance of: A) Ghost shrimp (*Neotrypaea californiensis*) zoea; B) Porcelain crab zoea; C) Larval fish during two tidal cycles within the South Slough estuary, OR. Shaded regions indicate night, open bars are samples from surface water, dark bars are samples from bottom water (adapted from Puls, 2001).

from the commensal pea crabs (Pinnotheridae), porcelain crabs (*Pachycheles* spp., *Petrolisthes* spp.) and other decapod crustaceans (*Hemigrapsus oregonensis* and *Neotrypaea californiensis*) are particularly abundant, and late stage megalopae from the cancrid crabs (*Cancer magister, C. productus*) sometimes enter the South Slough estuary in enormous numbers.

Meroplanktonic larvae from some species of marine and estuarine invertebrates are exported from the estuarine tidal waters while others are imported from sources outside the South Slough. For example, Puls (2001) monitored input and export of ghost shrimp larvae (*N. californiensis*) from the South Slough estuary and found that 99.6 % (of nearly 23,000 larvae captured) were small first stage zoeae. Moreover, the highest concentrations of *N. californiensis* zoea occurred in surface waters during nocturnal ebb tides and in bottom water immediately following nocturnal ebb tides (Figure 3.6). Predominance of young larval stages in the zooplankton assemblage suggests that *N. californiensis* larvae undergo vertical migrations and are exported from the South Slough into the nearshore region where they complete their period of planktonic development. In contrast, porcelain crab larvae occurred in greatest abundance in the South Slough during flooding tides, suggesting that they are imported into the estuary from outside sources (Puls, 2001; Figure 3.6). Molluscan veliger and pediveliger larvae from several bivalves (*i.e., Macoma nasuta, M. balthica, M. inquinata, Mya arenaria*, and *Cryptomya californica*) sometimes occur in considerable numbers in the water column throughout the South Slough estuary.

3.2.3.b Ichthyoplankton

The South Slough estuary is an essential nursery area for diverse communities of larvae and juveniles of many species of marine and estuarine fish (Figure 3.7). Fish larvae and juveniles of 24 species representing 12 families were collected in light traps deployed in the northern region of the South Slough (Miller, 2001; Table 3.1). The light traps were situated so they would provide representative samples of ichthyplankton communities from marine waters on flood tides and estuarine waters during ebb tides. Larval fish belonging to the families Cottidae, Clupeidae, Engraulidae, Gobiidae, Osmeridae, and Scorpaenidae are particularly abundant within the tidal waters of the South Slough (Miller, 2001; Puls, 2001).

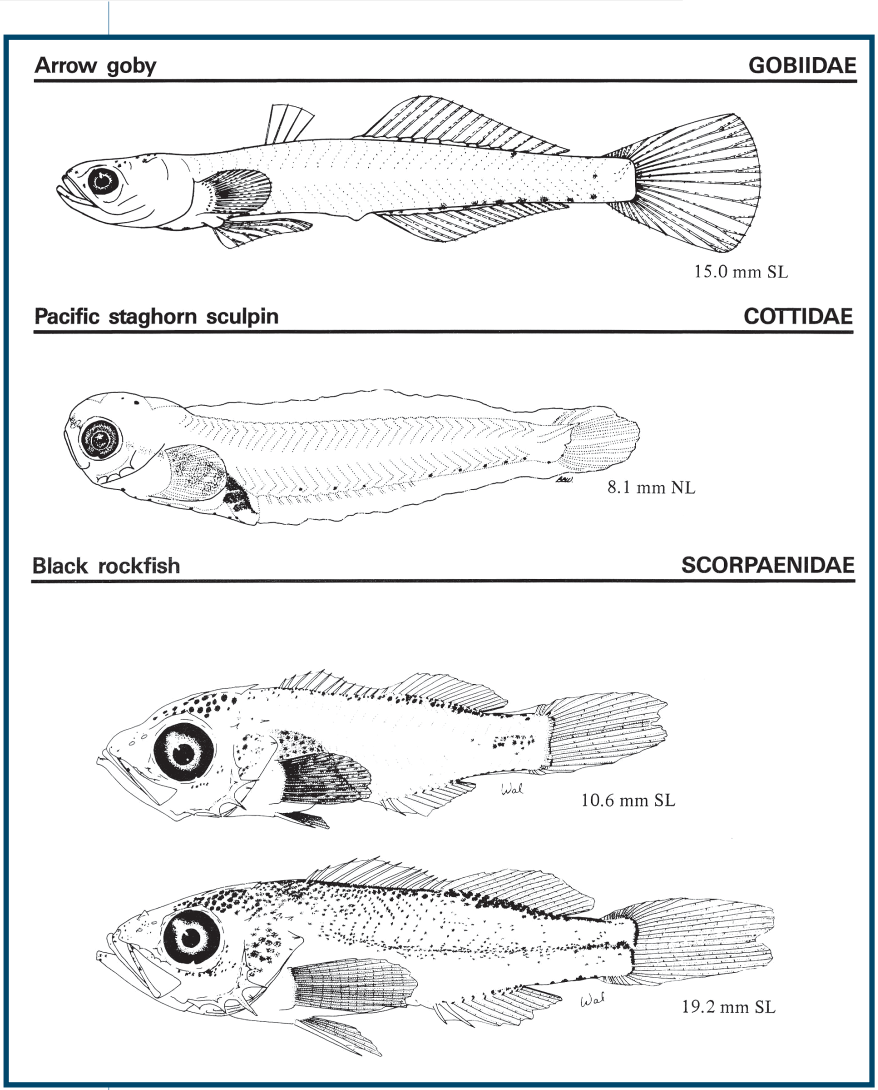


Figure 3.7. Representative juvenile fish captured within the South Slough estuary, OR (from Matarese *et al.*, 1989).

Table 3.1. List of juvenile fish species collected in light traps placed in the Coos estuary and South Slough (from Miller, 2001).

Genus and species	Common name	*Genus and species*	Common name
Ammodytes hexapterus	Pacific sandlance	*Hexagrammos decagrammus*	Kelp greenling
Apodichthys flavidus	Penpoint gunnel	*Hypomesus pretiosus*	Surf smelt
Artedius fenestralis	Padded sculpin	*Leptocottus armatus*	Staghorn sculpin
Ascelichthys rhodorus	Rosylip sculpin	*Oligocottus rimensis*	Saddleback sculpin
Clinocottus acuticeps	Sharpnose sculpin	*Ophidon elongatus*	Lingcod
Clinocottus globiceps	Mosshead sculpin	*Pholis ornata*	Saddleback gunnel
Cottus asper	Prickly sculpin	*Pleuronichthys coenosus*	C-O sole
Engraulis mordax	Northern anchovy	*Sardinops sagax*	Pacific sardine
Enophyrs bison	Buffalo sculpin	*Sebastes caurinus*	Copper rockfish
Gasterosteus acculeatus	Threespine stickleback	*Sebastes melanops*	Black rockfish
Gobiesox maeandricus	Northern clingfish	*Syngnathus leptorhynchus*	Bay pipefish
Hemilepidotus hemilepidotus	Red Irish Lord		

Larvae from free-spawning marine species, such as Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*), enter the Coos estuary and South Slough during winter months on flooding spring tides a few days after the initiation of offshore downwelling events. Larval fish (3-5 mm) from these species occur at the mouth of the estuary for only a brief period, while traps located further up the estuary continue to capture larger juveniles (> 20 mm) throughout the year. This pattern is consistent with the hypothesis that winter spawning may be an adaptation to minimize loss of fish larvae due to offshore advection, and that larvae and juveniles from *S. sagax* and *E. mordax* remain in the estuary for extended periods once they enter the tidal waters.

In contrast, the abundance of larval and juvenile rockfish (*Sebastes* spp.) is correlated directly with alongshore windstress, suggesting operation of another transport mechanism. Puls (2001) found that the abundance of planktonic larvae from estuarine gobies (Gobiidae) was consistently highest within the low density, low salinity estuarine tidal waters, and that larval gobies were rare in the higher salinity marine waters that entered South Slough from the lower marine-dominated region of Coos Bay (Figure 3.6). Larvae from the arrow goby (*Clevelandia ios*) and bay goby (*Lepidogobius lepidus*) were caught almost exclusively in bottom waters during the daylight hours. This pattern suggests that larvae from these burrowing bottom fish with adhesive demersal eggs are probably retained in the estuary rather than exported or imported (Puls, 2001). Hydrodynamic flushing of the shallow tideflats and deeper channels is most likely the primary factor in determining the probability of larval retention and the distribution of icthyoplankton in the South Slough estuary.

3.2.4 Nekton and Midwater Fish

Nekton communities within the South Slough estuary consist largely of free-swimming mysids and midwater fish. Like other estuaries in the Pacific northwest region, swarms of mysids (*Neomysis mercedis*) often occur in the low salinity shallow riverine regions of Winchester Creek, an area that receives substantial seasonal influence from freshwater. Mysid swarms are commonly located at the point where secondary tidal creeks discharge into the primary tidal channel, and among the submerged branches of fallen trees. Euryhaline individuals of *N. mercedis* can tolerate salinity conditions that range from freshwater to entirely marine, and they serve as prey items for shrimp and several species of estuarine fish. Smaller individuals of *Holmesimysis* spp. sometimes occur in the water column and among blades of eelgrass (*Zostera marina*) in the marine and riverine regions of the South Slough estuary.

Open water and tidal channels of the South Slough provide habitat for diverse communities of midwater fish, including the vast majority of species that are almost entirely marine, estuarine and anadromous (Bottom *et al.,* 1988). Shallow tidal channels and tideflat habitats within the South Slough estuary provide refuges from predators and productive forage areas for the postlarval, juvenile, and adult stages for over 30 species of fishes. Shiner perch, white seaperch, Pacific herring, Walleye surfperch, topsmelt, surf smelt, pile perch, American shad, silver surfperch and northern anchovy are all common members of the midwater fish assemblage (Table 3.2, Figure 3.8).

Shiner perch (*Cymatogaster aggregata*) are by far the most abundant fish in the South Slough estuary where they constitute 76% of the individuals and nearly 60% of the biomass of fish captured in seine surveys (Table 3.2). Shiner perch often swarm in the shallow tidal channels and eelgrass beds during summer feeding and breeding aggregations, and their viviparous reproductive mode ensures that juveniles occur in habitats that are conducive to life as adults. White seaperch (*Phanerodon furcatus*) are also common in the tidal channels, particularly around old pilings and submerged tree limbs. Pacific herring (*Clupea harengus pallasi*) and topsmelt (*Atherinops affinis*), along with surf smelt (*Hypomesus pretiosus*), are predominantly marine species that school off the sandy beaches at the mouth of the Coos estuary and occasionally enter the South Slough where they move throughout tidal channels during flood tides. The prickly sculpin (*Cottus asper*) is a predominantly freshwater species that often ventures into the brackish water of the estuary. Threespine stickleback (*Gasterosteus aculeatus*) is another predominantly freshwater species that often forages along the margins of freshwater tidal creeks and among the emergent vegetation of fresh and salt marshes.

Richness of fish communities that occur in the tidal channels decreases along the South Slough estuarine gradient, with the greatest number of species found in the deeper marine-dominated region and fewest species in the shallow riverine region (Figure 3.8). The number of species in the tidal channels at low tide was always greater than the number of species found over the tideflats at high tide. This distribution pattern

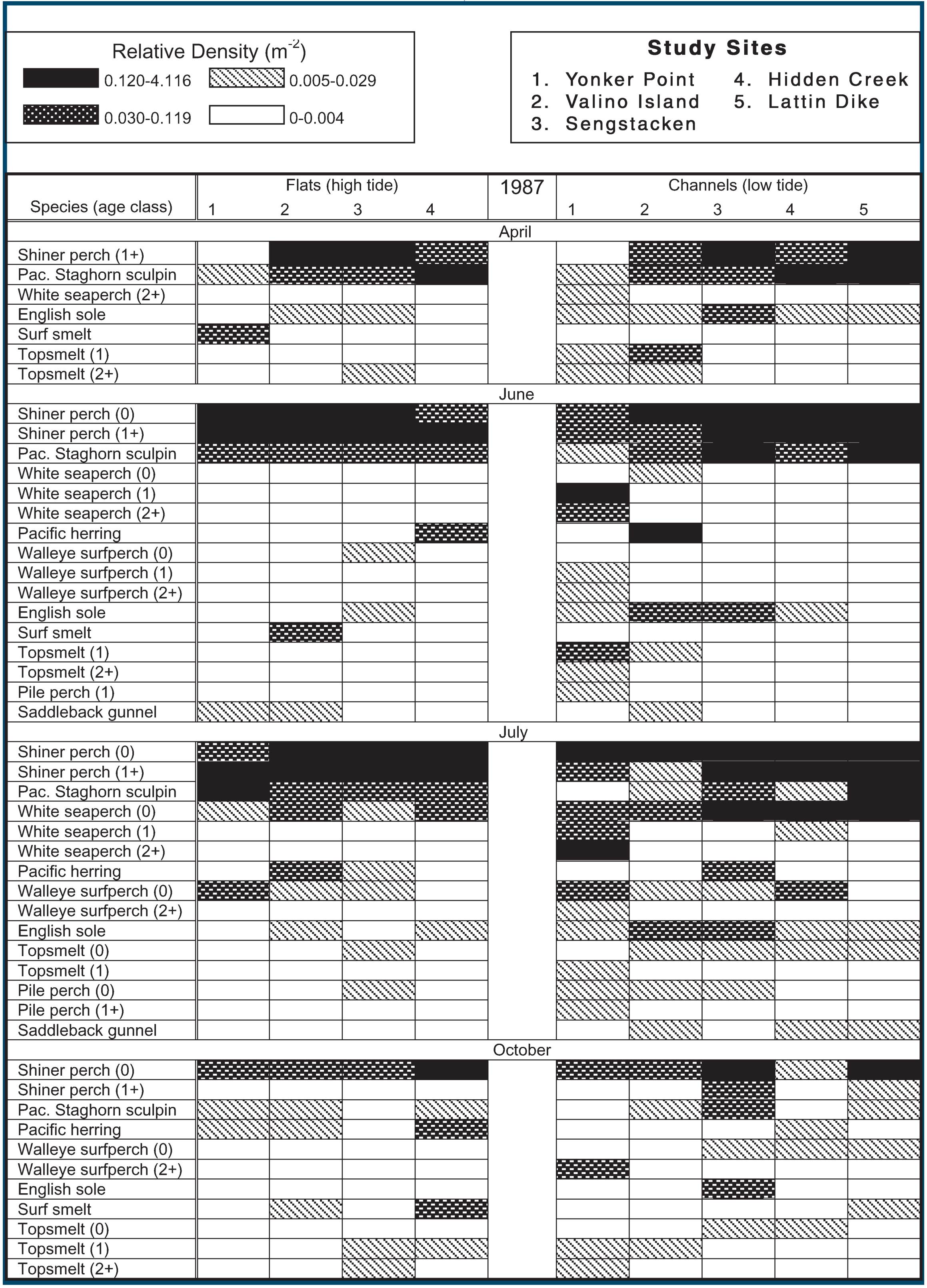
Table 3.2. Total abundance and biomass (g wet weight) of fish species captured during 1987 at five sampling stations in the South Slough estuary, OR (from Bottom *et al.*, 1988).

Species Common name, *scientific name*	Totals No.	% No.	Mass (g)	% Mass
Shiner perch, *Cymatogaster aggregata*	24,734	75.9	236,227.6	58.5
Pacific staghorn sculpin, *Leptocottus armatus*	2,901	8.9	19,439.9	4.8
White seaperch, *Phanerodon furcatus*	1,652	5.1	61,134.1	15.1
Pacific herring, *Clupea pallasi*	578	1.8	1,455.4	0.4
Walleye surfperch, *Hyperprosopon argenteum*	552	1.7	18,488.1	4.6
English sole, *Pleuronectes vetulus*	526	1.6	3,187.2	0.8
Topsmelt, *Atherinops affinis*	465	1.4	27,826.7	6.9
Surf smelt, *Hypomesus pretiosus*	465	1.4	1,982.1	0.5
Pile perch, *Rhacochilus vacca*	150	0.5	23,793.2	5.9
Saddleback gunnel, *Pholis ornata*	128	0.4	668.2	0.2
American shad, *Alosa sapidissima*	96	0.3	483.2	0.1
Silver serfperch, *Hyperprosopon ellipticum*	75	0.2	949.8	0.2
Starry flounder, *Platichthys stellatus*	67	0.2	5,726.7	1.4
Chinook salmon, *Oncorhynchus tshawytscha*	43	0.1	750.3	0.2
Striped seaperch, *Embiotica lateralis*	33	0.1	1,248.1	0.3
Northern anchovy, *Engraulis mordax*	22	0.1	63.9	<0.1
Bay pipefish, *Syngnathus leptorhynchus*	21	0.1	52.2	<0.1
Kelp greenling, *Hexagrammos decagrammus*	11	<0.1	99.0	<0.1
Coastal cutthroat trout, *Onchorhynchus clarki clarki*	6	<0.1	84.5[a]	-
Lingcod, *Ophiodon elongatus*	6	<0.1	57.3	0.1
Rockfish, *Sebastes* spp.	6	<0.1	22.9	<0.1
Bay goby, *Lepidogobius lepidus*	5	<0.1	25.0	<0.1
Coho salmon, *Oncorhynchus kisutch*	5	<0.1	135.3	<0.1
Speckled sanddab, *Citharichthys stigmaeus*	5	<0.1	19.0	<0.1
Chum salmon, *Oncorhynchus keta*	4	<0.1	13.4	<0.1
Cabezon, *Scorpaenichthys marmoratus*	3	<0.1	14.6	<0.1
Pacific tomcod, *Microgadus proximus*	2	<0.1	12.2	<0.1
Green sturgeon, *Acipenser medirostris*	1	<0.1	NW[b]	-
Pacific sand lance, *Ammodytes hexapterus*	1	<0.1	3.2	<0.1
Penpoint gunnel, *Apodichthys flavidus*	1	<0.1	1.1	<0.1
Prickly sculpin, *Cottus asper*	1	<0.1	12.2	<0.1
Steelhead, *Oncorhynchus mykiss*	1	<0.1	NW[b]	-
Threespine stickleback, *Gasterosteus aculeatus*	1	<0.1	0.5	<0.1
Total	**32,567**		**403,976.9**	

[a] Weight represents only 2 of the 6 fish sampled. The weight of 4 adult trout exceeded the capacity of the balance.
[b] NW=no weight available because size of individuals exceeded capacity of the balance.

suggests that fish migrate across the tideflats to forage during flooding tides and then return to the channels during the tidal ebb.

Several of the fish found within the South Slough are known to reproduce in Pacific northwest estuaries. Pleuronectids (flounders and sole), embiotocids (surfperch), osmerids (smelts), and salmonids (salmon and trout) are known to use estuarine habitats as nurseries for juveniles (Pearcy and Myers, 1974; Misitano, 1977; Simenstad, 1983). With the exception of the viviparous embiotocids and anadromous salmonids, however, little is known about the specific habitats used for spawning and rearing of early juvenile fish. Adults of several embiotocids (white seaperch, Walleye surfperch, pile perch) do not appear in the South Slough until summer (June) and they rarely occur in the riverine region of the estuary. The narrow distribution of these perch suggests that the tidal channel below Valino Island (or possibly further upstream on the high tide) may serve as a seasonal staging area for parturition. Topsmelt are known to attach their eggs to blades of intertidal algae, and the adults and juveniles feed on estuarine plant material (Nordby, 1982; Emmett *et al.*, 1991), but their



Relative Density (m^{-2})
■ 0.120-4.116
▨ 0.005-0.029
▦ 0.030-0.119
☐ 0-0.004

Study Sites
1. Yonker Point
2. Valino Island
3. Sengstacken
4. Hidden Creek
5. Lattin Dike

Species (age class)	Flats (high tide)				1987	Channels (low tide)				
	1	2	3	4		1	2	3	4	5
April										
Shiner perch (1+)		■	■	▦			▦	■	▦	■
Pac. Staghorn sculpin	▨	▦	▦	■		▨	▦	▦	■	■
White seaperch (2+)						▨				
English sole		▨	▨			▨	▨	▦	▨	▨
Surf smelt	▦									
Topsmelt (1)						▨	▦			
Topsmelt (2+)			▨			▨	▨			
June										
Shiner perch (0)	■	■	■	▦		▦	■	■	■	■
Shiner perch (1+)	■	■	■	■		▦	▦	■	■	■
Pac. Staghorn sculpin	▦	▦	▦	▦		▨	▦	■	▦	■
White seaperch (0)							▨			
White seaperch (1)						■				
White seaperch (2+)						▦				
Pacific herring				▦			■			
Walleye surfperch (0)			▨							
Walleye surfperch (1)						▨				
Walleye surfperch (2+)						▨				
English sole			▨			▨	▦	▦	▨	
Surf smelt		▦								
Topsmelt (1)						▦	▨			
Topsmelt (2+)						▨				
Pile perch (1)						▨				
Saddleback gunnel	▨	▨					▨			
July										
Shiner perch (0)	▦	■	■	■		■	■	■	■	■
Shiner perch (1+)	■	■	■	■		▦	▨	■	■	■
Pac. Staghorn sculpin	■	▦	▦	▦			▨	▦	▨	■
White seaperch (0)	▨	▦	▨	▦		▦	▦	■	■	■
White seaperch (1)						▦			▨	
White seaperch (2+)						■				
Pacific herring		▦	▨					▦		
Walleye surfperch (0)	▦	▨	▨			▦	▨	▨	▦	
Walleye surfperch (2+)						▨				
English sole		▨		▨		▨	▦	▦	▨	▨
Topsmelt (0)			▨				▨	▨	▨	▨
Topsmelt (1)						▨				
Pile perch (0)			▨			▨	▨	▨		
Pile perch (1+)						▨				
Saddleback gunnel							▨		▨	▨
October										
Shiner perch (0)	▦	▦	▦	■		▦	▦	■	▨	■
Shiner perch (1+)								▦		▨
Pac. Staghorn sculpin	▨	▨		▨			▨	▦		▨
Pacific herring	▨	▨		▦					▨	
Walleye surfperch (0)								▨	▨	▨
Walleye surfperch (2+)						▦				
English sole								▦		
Surf smelt		▨		▦						▨
Topsmelt (0)								▨	▨	
Topsmelt (1)			▨	▨		▨	▨			
Topsmelt (2+)			▨			▨				

Figure 3.8. Seasonal differences in the density and distribution of fish in the South Slough estuary, OR in 1987 (adapted from Bottom *et al.*, 1988).

Table 3.3. Total estimated production (P: g wet wt/m^2) and mean biomass density (B: g wet wt/m^2) for common fish species collected on tideflats and in channels of the South Slough estuary, OR (April-October 1987; adapted from Bottom *et al.,* 1988).

	Flats (high tide)			Channels (low tide)		
Species	**Total P**	**% P**	**B**	**Total P**	**% P**	**B**
Shiner perch	2.343	71.4	5.284	8.158	68.3	8.015
Staghorn sculpin	0.635	19.4	0.383	0.951	8.0	0.593
Surf smelt	0.109	3.3	0.071	0.012	0.1	0.018
Starry flounder	0.105	3.2	0.101	0.084	0.7	0.145
English sole	0.036	1.1	0.024	0.249	2.1	0.122
Pacific herring	0.028	0.8	0.042	0.031	0.3	0.024
Chinook salmon	0.011	0.3	0.004	0.079	0.7	0.028
Saddleback gunnel	0.005	0.2	0.006	0.002	<0.1	0.022
Walleye surfperch	0.003	0.1	0.024	0.211	1.8	0.679
White seaperch	0.002	0.1	0.066	1.584	13.3	2.280
Topsmelt	0.002	0.1	0.546	0.563	4.7	0.610
Pile perch	-	-	0.002	0.014	0.1	0.895
Total	**3.279**		**6.553**	**11.938**		**13.431**

spawning sites have not been identified within the South Slough. Differences in estuarine habitat (channels or tideflats) had an overriding influence on species richness of fish communities within the South Slough (Bottom *et al.,* 1988). The majority of transient marine and anadromous species (*i.e.,* striped seaperch, rockfish, northern anchovy, speckled sanddab, coho salmon, and coastal cutthroat trout) were captured exclusively in the channels at low tide.

The composition and spatial distribution of fish assemblages also changes seasonally within the South Slough estuary. In general, assemblages of estuarine fish are most diverse in the summer months and least diverse in the fall and winter (Figure 3.8). Maximum species richness and abundance of estuarine fish in summer is correlated with the migratory behavior of adults and the use of upper regions of the estuary as a rearing area for juveniles. For example, adult shiner perch and Pacific staghorn sculpin are widespread throughout the channels and tideflats of the South Slough in the spring and summer. At low tide both of these species become more abundant in the small tidal creeks within the southern riverine region of the estuary. Shiner perch are known to aggregate into loose schools that migrate seasonally onshore into the shallow water of bays and estuaries in the spring, and offshore into deeper marine waters in the fall and winter (Emmett *et al.,* 1991).

During the summer months, juvenile (age 0) shiner perch occur throughout the estuary, and adults reached their maximum abundance of 6 fish m^{-2} near Lattin Marsh in June. Pacific staghorn sculpin migrate from the marine dominated region of the estuary in the winter and into the more freshwater regions in the spring and summer. Larger individuals of *L. armatus* migrate locally into the deeper marine waters as they grow (Emmett *et al.,* 1991). Adult topsmelt also migrate into the South Slough estuary in the spring and summer to spawn, although they occur primarily in the channels within the northern marine-dominated region of the estuary. Adult pile perch, two distinct age classes of adult white seaperch, and adult topsmelt occur in the low tidal channels in the northern region, but they were not observed over the tideflats. High densities of juvenile Pacific herring also occurred in the channels in the summer, and they appeared to move onto the tideflats further up the estuary at high tides. Juvenile (age 0) topsmelt first appear in the tidal channels in July.

In the fall, fish densities declined in the estuary and shiner perch remained the most abundant species in the channels and over the tideflats at a low density of 1 fish per 5 m^2. Older age classes of topsmelt occurred in the low tide channels and spawning adults were captured at high tide over the tideflats in both the Sengstacken and Winchester arms of the South Slough.

Measurements of total fish biomass and production (change in biomass over the sampling interval) were greater in the South Slough channels at low tide com-

Table 3.4. Estimated mean standing crop (kg wet weight) for common species and age classes (year) of fish within the South Slough estuary, above Collver Point (April-October 1987). Standing crop values are used to classify fishes as ebb-tide migrants (+) or non-migrants (o). Movements of fishes that reside primarily in channels cannot be inferred (?), since channels were not sampled at high tide (adapted from Bottom *et al.*, 1988).

Species (age class)	Mean standing crop (kg) Flats (high tide)	Channels (low tide)	Principal habitat use (F=flats, C=channels)	Net movement ebb tide
Shiner perch (1+)	18,400.8	5,274.6	F, C	+
Shiner perch (0)	1,872.3	1,219.7	F, C	+
Topsmelt (2+)	1,835.4	263.7	F, C	+
Pacific staghorn sculpin	1,469.8	480.5	F, C	+
Starry flounder (1)	312.3	54.4	F, C	+
Surf smelt (0)	273.6	6.6	F	+
Topsmelt (1)	251.7	225.4	F, C	o
White seaperch (0)	244.8	150.1	F, C	o
Pacific herring (0)	138.5	9.9	F	+
English sole	92.1	98.7	F, C	o
Walleye surfperch (0)	91.7	69.0	F, C	o
Saddleback gunnel	23.4	17.7	F, C	o
Pacific herring (1+)	21.5	9.5	F, C	o
Starry flounder (0)	15.3	5.4	F, C	o
Chinook salmon (0)	13.4	22.6	F, C	o
Pile perch (0)	8.4	19.0	F, C	o
Walleye surfperch (1)	7.3	20.9	F, C	o
Topsmelt (0)	6.5	5.3	F, C	o
White seaperch (2+)	0	1,423.0	C	?
Pile perch (1+)	0	706.2	C	?
Walleye surfperch (2+)	0	460.6	C	?
White seaperch (1)	7.3	274.0	C	?
Surf smelt (1)	0	8.1	C	?
Total	**25,086.1**	**10,824.9**		

pared with the tideflats at high tide (Bottom *et al.*, 1988). Total estimates of fish production for the period April to October were 3.3 g wet weight m^{-2} for fish sampled at high tide on the flats and 11.9 g wet weight m^{-2} for fish collected at low tide in the channels (Table 3.3). The greatest increase in fish biomass occurred during a six-week interval between sampling periods in June and July, and it is estimated that about 40% of the total fish production for the entire survey occurred between July and October. Shiner perch and staghorn sculpin accounted for 90% of the fish production measured on the tideflats and 76% of the fish production in the channels. While there was minimal production of white seaperch, walleye surfperch, and topsmelt on the tideflats, together these species accounted for 20% of the production estimated at low tide in the channels. Greater species richness and biomass observed in the tidal channels, however, may be an artifact of sampling high density fish assemblages in the channel at low tide compared with sampling of low density assemblages over the tideflats at high tide. When estimates of total fish biomass are adjusted to take into account the extensive spatial extent of intertidal flats in the South Slough estuary, mean standing crop of fishes in the tidal flats (25,086 kg wet weight) is over twice that in the channels (10,825 kg wet weight; Table 3.4). These estimates suggest that migration into the intertidal flats on flood tides is an important ecological event for several species, particularly shiner perch, adult topsmelt (2+ age class), Pacific staghorn sculpin, starry flounder, juvenile surf smelt, northern anchovy, and juvenile Pacific herring.

Fish communities from the South Slough estuary can be divided into three principal assemblages based on differences in their temporal and spatial patterns of distribution (Table 3.5). The first group (Assemblage I / Upper South Slough) includes the most widespread and abundant fishes in the South Slough estuary as well as the earliest arrivals to the uppermost nursery areas. These are the juvenile and adult shiner perch, Pacific staghorn sculpin, and juvenile white seaperch.

The second group (Assemblage II / Lower South Slough Channels) consists of many of the largest and oldest age classes of fish. Most members of this second group did not appear in the estuary until June, and they were distributed almost exclusively in the northern marine-dominated region of the estuary. These adult fishes (white seaperch, walleye surfperch, topsmelt, and pile perch) did not migrate onto the tideflats nor into the upper reaches of the Sengstacken and Winchester arms where juvenile fish were abundant.

The third group (Assemblage III / Middle Estuary) was intermediate in distribution and included a few species that arrived in the South Slough in April from ocean-spawning adults (*i.e.,* English sole and surf smelt) as well as later recruits from the earlier Assemblage II spawners (walleye surfperch, topsmelt, and pile perch). The abundance of Assemblage III fishes was typically low in the Winchester arm of the South Slough but high densities of these fishes frequently occurred in the Sengstacken arm.

3.3 Tidal Channels and Subtidal Habitat

Tidal channels and subtidal habitats within the South Slough estuary support diverse communities of marine and estuarine species. Although the hydrological circulation pattern within the South Slough is not completely understood (Juza, 1995), direct connection of the estuarine tidal channel to the lower region of Coos Bay and the nearshore Pacific Ocean fosters development of rich floral and faunal assemblages. Taxonomic composition of these communities reflects seasonal, annual, and interannual differences in the extent of oceanic influence and freshwater inputs. Species richness within the tidal channels and subtidal habitats of South Slough is relatively high compared to other tidal inlet systems that drain into Coos Bay (Ednoff, 1970; Roye, 1979).

Table 3.5. Classification of fish assemblages in the upper region along the South Slough estuarine gradient, OR during 1987. Distribution is expressed as station(s) of greatest abundance. 1. Marine-dominated (Younker Point); 2. Marine-dominated / mesohaline (Valino Island); 3. Mesohaline (Elliott Creek Mouth); 4. Mesohaline (Hidden Creek); 5. Mesohaline / riverine (Lattin Dike; adapted from Bottom *et al.*, 1988).

Species (age class)	Time of peak abundance	Peak distribution Flats	Channels
Assemblage I. Upper Slough			
Shiner perch (0)	June	1,2,3	2,4,5
Shiner perch (1+)	June	2,4	3,4,5
Pacific staghorn sculpin	April	2,4	4,5
White seaperch (0)	July	2,4	3,5
Assemblage II. Lower Slough Channels			
White seaperch (1, 2+)	June	-	1
Walleye surfperch (1,2+)	June-October	-	1
Topsmelt (1,2+)	April-June, October	3	1,2
Pile perch (1+)	June-July	-	1
Assemblage III. Intermediate Stations / Upper Sengstacken Arm			
Walleye surfperch (0)	July	1	1,4
English sole	April-July	4	2,3,4
Topsmelt (0)	July, October	3,4	2,3,4
Pile perch (0)	July	3	1,2,3,4
Saddleback gunnel	June-July	1,2	2,4
Pacific herring (0)	June	2,4	2,3
Surfsmelt (0)	June	3.4	-

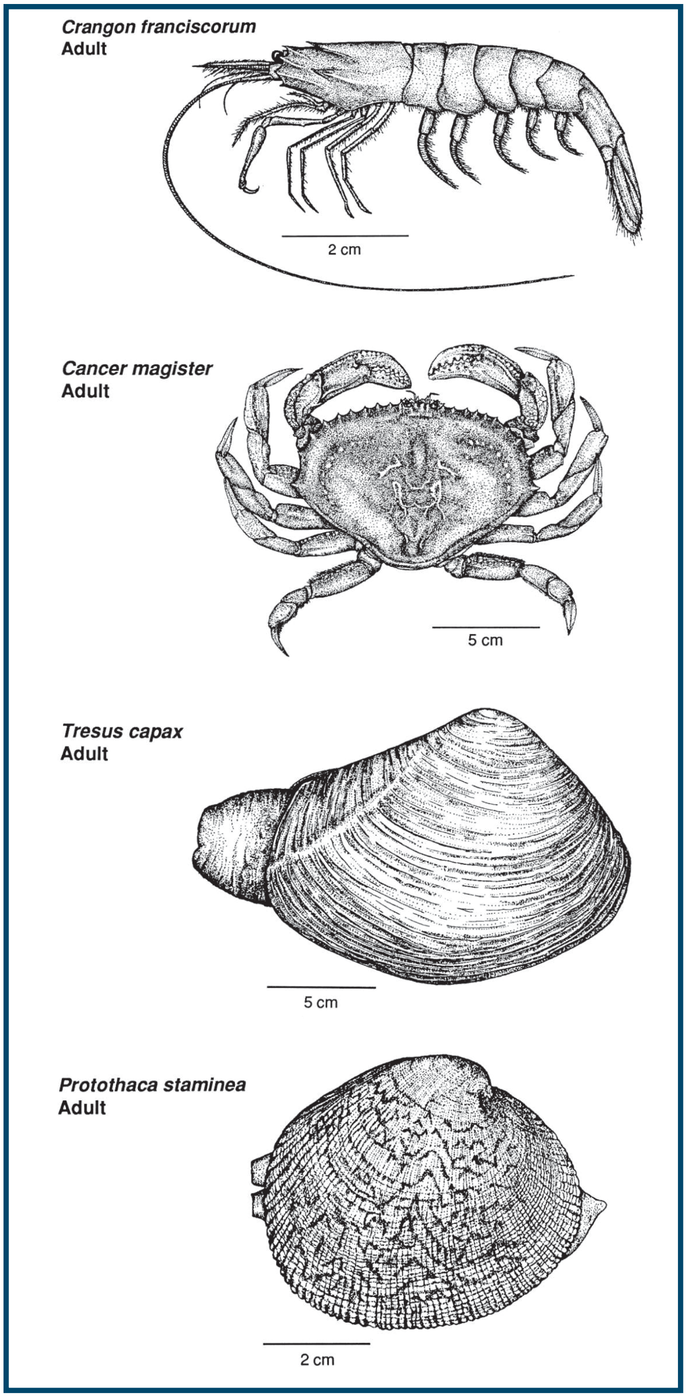


Figure 3.9. Subtidal invertebrates that inhabit the northern region of the South Slough tidal channel (from Emmett *et al.*, 1991).

3.3.1 Subtidal Macroalgae

A small bed of bull kelp (*Nereocystis luetkeana*) is a consistent and persistent feature in the subtidal channel at Long Island Point. This annual species flourishes along the exposed rocky reefs outside the Coos estuary, and they are torn loose from the substratum during storms and high waves. The bull kelp drift into the South Slough and the strong holdfasts carry rocks into the estuary where they accumulate in the soft subtidal sand and mud. The bull kelp bed at Long Island Point functions as a pseudopopulation because the estuarine habitat is sufficient for the floating blades to produce sori and reproductive spores (observed in the summer and fall), but the muddy substratum and turbid waters of the South Slough are not conducive to recruitment of young bull kelp.

3.3.2 Subtidal and Sublittoral Invertebrates

Benthic invertebrate communities have not been systematically investigated throughout the subtidal channels of the South Slough estuary. Although core samples and bottom grabs have been collected on a sporadic basis, baseline descriptive and quantitative information is lacking for the large deep burrowing bivalves, motile crustaceans, and infaunal invertebrates.

Anecdotal observations of faunal assemblages identified from baited crab traps, occasional trawl surveys, and SCUBA dives confirms that subtidal channels in the northern marine-dominated region of the South Slough are inhabited by brachyuran crabs, caridean shrimp, bivalves, seastars, and gastropods (Figure 3.9). Conspicuous members of the subtidal invertebrate assemblage include Dungeness crabs (*Cancer magister*), red rock crabs (*C. productus*), and sometimes juveniles of the Oregon crab (*C. oregonensis*). Individuals of the northern kelp crab (*Pugettia producta*), graceful kelp crab (*Pugettia gracilis*), and black-clawed crab (*Lophopanopeus bellus*) have been observed on log pilings, in drift algae, and among canopies of eelgrass (*Zostera marina*) in the lowest intertidal zone (pers. observation). Several species of shrimp (*i.e.,* California bay shrimp, *Crangon franciscorum*; Alaskan gray shrimp, *C. alaskensis*; bay shrimp, *C. nigricauda*; broken back shrimp, *Heptacarpus paludicola*; glass shrimp, *H. pictus*; sand shrimp, *Lissocrangon stylirostris*; northern hooded shrimp, *Betaeus harrimani*; grass shrimp, *Hippolyte clarki*) occur in the subtidal sand, mud, and shell rubble habitat, and individuals of the mud shrimp (*Upogebia pugettensis*) inhabit permanent burrows in the low intertidal and shallow subtidal zone.

A diverse assemblage of bivalve molluscs is also present including cockles (*Clinocardium nuttallii*), bent-nosed clams (*Macoma nasuta*), sand clams (*M. secta*), irus clams (*Macoma inquinata*), butter clams

(*Saxidomus giganteus*), littleneck clams (*Protothaca staminea*), soft-shell clams (*Mya arenaria*), and gaper clams (*Tresus capax*). Boring clams (*Adula californiensis, Penitella penita*, and *Zirfaea pilsbryi*) excavate burrows in the subtidal sedimentary bedrock at Collver Point, and northwest shipworm clams (*Bankia setacea*) bore into log pilings and submerged wood. Commensal pea crabs (*i.e., Pinnixa* spp.) inhabit the cavities of many species of burrowing clams. The moon snail (*Polinices lewisii*) inhabits sandy and muddy bottom sediments where it is often buried and preys upon bivalves and other snails. Other molluscs include rare individuals of the snails (*Olivella biplicata* and *Nucella lamellosa)*, the dorid nudibranch *Archidoris montereyensis*, and the lined chiton *Mopalia lignosa*. Several ochre seastars (*Pisaster ochraceus*) have been observed subtidally within shell rubble habitat in the northern region of the estuary where they most likely occur in association with dock pilings and cement supports for the Charleston Bridge. Large individuals of the pink seastar *Pisaster brevispinus* roam the subtidal surface sediments to feed on infaunal invertebrates and cockles, and they also dig large holes to excavate buried butter clams, gaper clams, and other bivalves.

Individuals of the Olympia oyster (*Ostrea conchaphila)* were historically abundant in the subtidal channels of Coos Bay and the South Slough estuary, and deposits of *O. conchaphila* shells occur in dredge spoils and shell middens along the shoreline of the South Slough (Baker *et al.,* 2000). Although the populations went locally extinct prior to European settlement, groups of Olympia oysters have since become re-established in the low intertidal and subtidal zone at several locations in Coos Bay. Only a few isolated individuals, however, were found in the Charleston Boat Basin, at the mouth of the South Slough estuary (Baker *et al.,* 2000). Subtidal shell rubble habitats located in areas that experience intermediate salinity ranges within the South Slough (*i.e.,* tidal channels in the vicinity of Long Island Point) appear to be suitable for recolonization by *O. conchaphila.*

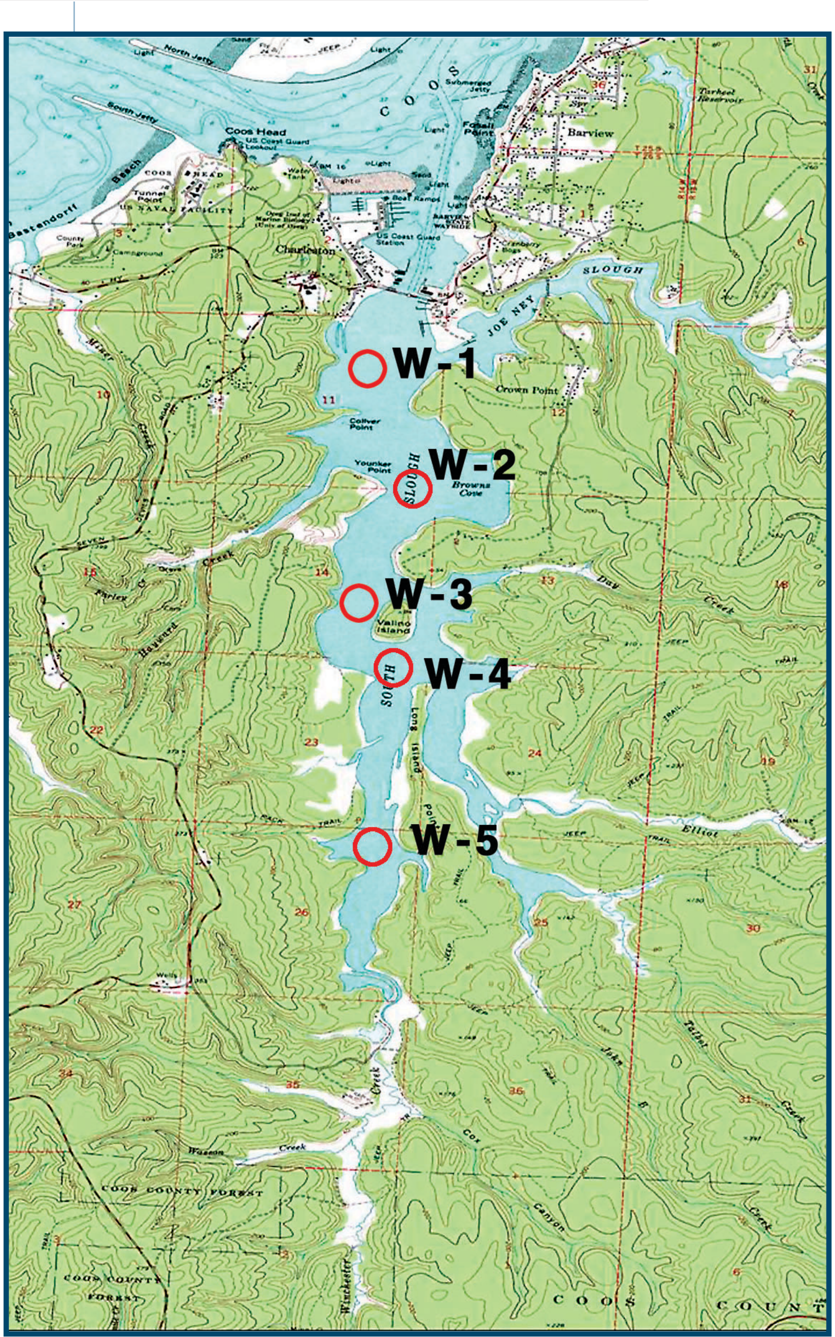


Figure 3.10. Location of sample stations for analysis of sublittoral invertebrate communities along the South Slough estuarine gradient, OR (adapted from Jefferts, 1977).

Sublittoral invertebrate assemblages were characterized along the South Slough estuarine gradient by core sampling in the soft sediment habitats (Jefferts, 1977). Invertebrate communities were surveyed within the subtidal channels and low intertidal flats of the northern and middle regions of the South Slough estuary in April of 1975 (Figure 3.10), prior to dredging of the Coos Bay navigational channel. Composition and abundance of the invertebrate faunal assemblages was compared between the dredged and undisturbed areas of the estuary to assess the potential ecological impacts of sediment removal and resuspension associated with

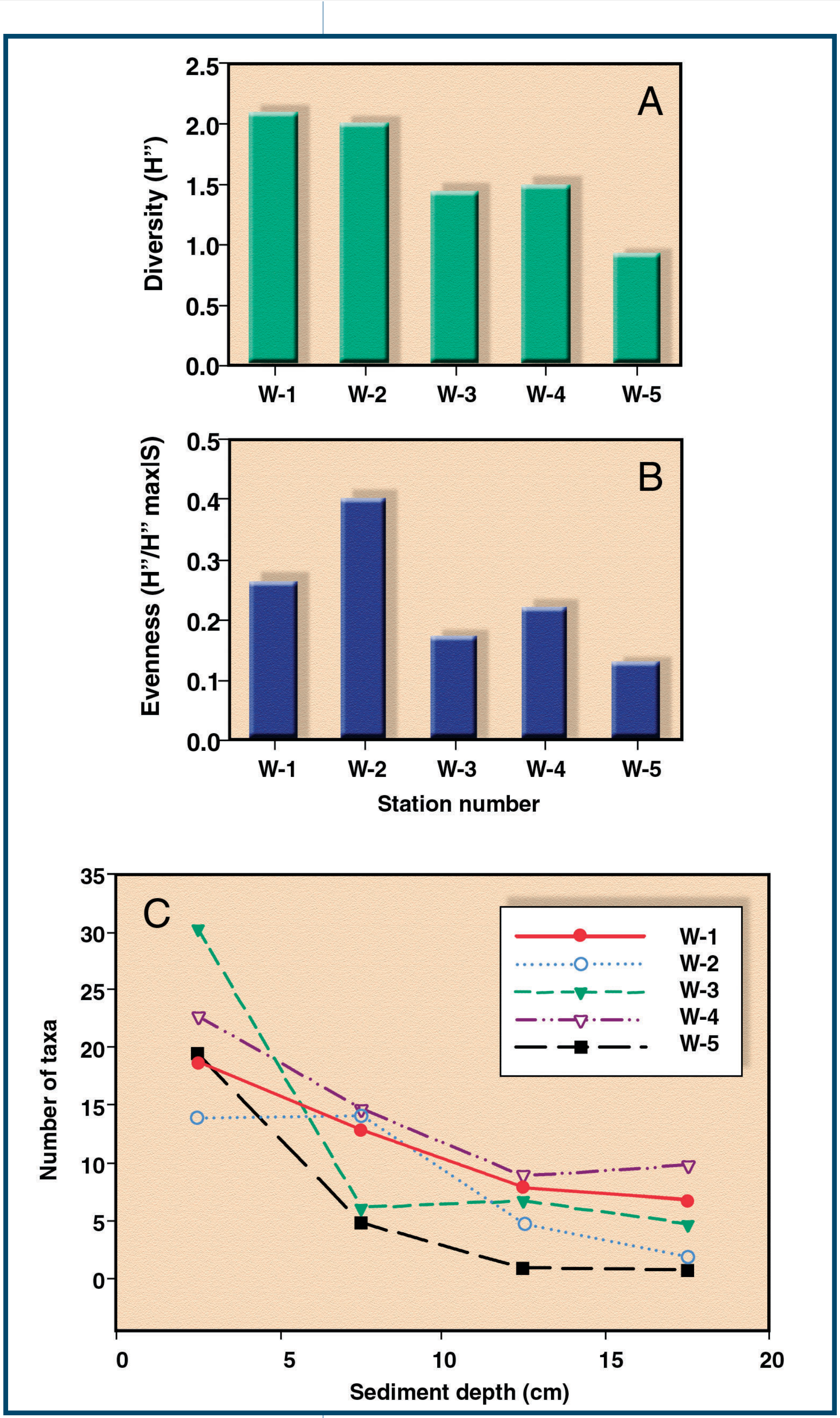


Figure 3.11. Characteristics of infaunal invertebrate communities within the South Slough estuary, OR. A. Species diversity (H"), and B. Community evenness (H"/H" max S) along the South Slough estuarine gradient. C. Relationship between number of invertebrate taxa and sediment depth for sample stations W1-W5 (see Figure 3.10 for station locations; adapted from Jefferts, 1977).

dredging. Although the sample sites within the South Slough tidal channels include a mixture of subtidal and low intertidal soft sediment habitats, they provide a representative characterization of the infaunal invertebrate communities that occur in the sublittoral regions of the South Slough estuary.

Jefferts (1977) described a rich invertebrate fauna from the South Slough estuary including 26 species of polychaetes, 10 bivalves, 4 harpacticoid copepods, and 7 amphipods. A subset of the samples collected from South Slough is presented in Table 3.6. The maximum number of invertebrate taxa occurred along the banks of the tidal channel immediately west of Valino Island (South Slough station W-3), while the uppermost South Slough station (Hidden Creek, W-5) exhibited the lowest taxonomic diversity (Figure 3.11). The Charleston Channel station is located in the northern marine-dominated region of the estuary, and the sandy-mud surface substratum contained a relatively low concentration of volatile solids (2.1%) and a low water content (20.6%). The invertebrate assemblage was dominated by tanaids (*Leptochelia dubia*), nematodes, oligochaetes, and a combination of polychaetes, bivalves, harpacticoid copepods, cumaceans, and amphipods (Table 3.6). Similarly, the Valino Island sample station is located near the southernmost extent of marine tidal waters, and the sandy-mud substratum contained a nearly identical concentration of volatile solids (2.0%) and a slightly elevated water content (27.3%). The invertebrate assemblage at Valino Island was also dominated by tanaids (*L. dubia*), nematodes, oligochaetes, and a combination of polychaetes, ostracods, amphipods, and fish eggs. In contrast, the Hidden Creek sample station is located in the middle mesohaline region of the estuary, and the muddy surface substratum contained a high concentration of volatile solids (8.0%) and a high water content (58.2%). The invertebrate assemblage at the Hidden Creek site was dominated by a few species of small burrowing polychaetes (*i.e., Fabricia sabella, Mediomastus acutus, Pygospio elegans*), oligochaetes, and nematodes (Table 3.6). All three of these polychaetes are opportunistic species that are well adapted to inhabit stressful soft-sediment environments (Jefferts, 1977). Their reproductive cycles are short and they are capable of outcompeting other organisms in the low oxygen, small grain size, aequeous substrata that characterize the middle mesohaline region of the South Slough estuary.

Sublittoral invertebrate assemblages in the northern marine-dominated region of the South Slough inhabit predominantly coarse sandy-mud sediments, and the infaunal invertebrates are distributed fairly deep in the sediment (Figure 3.11). Presumably, the coarse-grained sediments are well-aerated and should allow infaunal organisms to burrow deep into the sediment and avoid predators on the surface. The invertebrate fauna from the South Slough estuary was consistently distributed deeper in the sediment compared to samples collected from upper regions of the Coos Bay shipping channel. By comparison with the South Slough estuary, the invertebrate faunal assemblage from the Coos Bay shipping channel is depauperate in species, and those species that occur are generally cosmopolitan, opportunistic, and restricted to the upper 10 cm of sediments. Invertebrate faunal assemblages from the upper region of Coos Bay (near the Coos Bay city dock) were similar to invertebrate assemblages in the northern region of South Slough (Figure 3.12). Conversely, the invertebrate assemblage sampled from a high current area near North Bend was most similar to the species group sampled from Long Island Point in the South Slough (another area characterized by swift tidal currents). Frequent disturbance of the bottom due to dredging, hydrodynamic swash generated by the passage of cargo ships, and industrial activity associated with the dredged channel appear to have a deleterious effect on faunal diversity in Coos Bay (Jefferts, 1977). Differences in

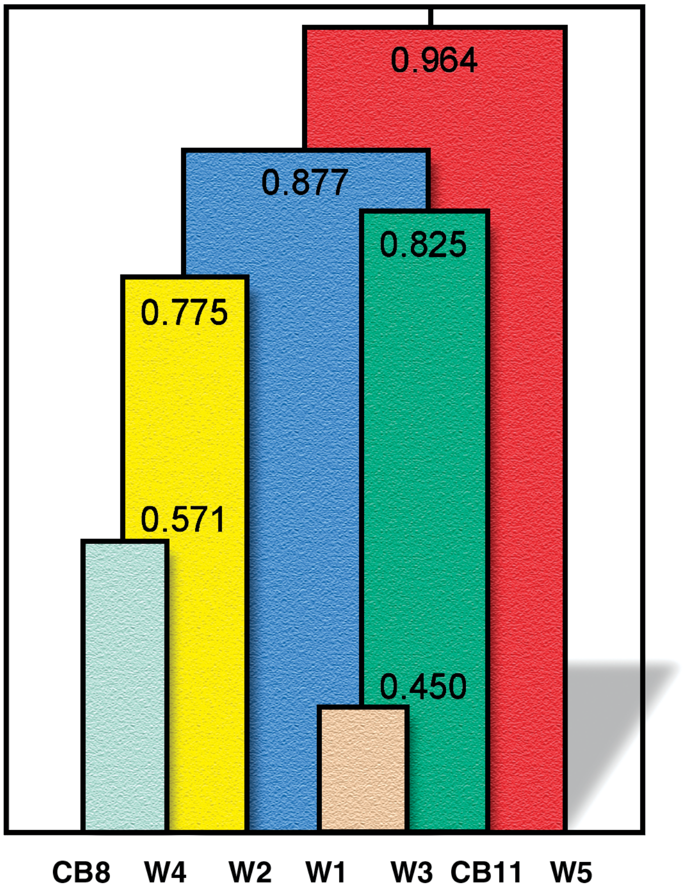


Figure 3.12. Agglomerative hierarchical cluster diagram of infaunal invertebrate assemblages within the South Slough estuary, OR. Stations within South Slough (W1-W5) are compared with stations from Coos Bay (CB8, CB11) using the Bray-Curtis dissimilarity index. BC values shown at cluster branches indicate relative dissimilarity between infaunal assemblages (see Figure 3.10 for locations of stations W1-W5; adapted from Jefferts, 1977).

Table 3.6. Composition, distribution, and abundance of sublittoral infaunal invertebrates from soft-sediment habitats along the estuarine gradient within the South Slough, OR. Values indicate no. individuals from upper 20 cm of sediment. Adapted from Jefferts (1977); core sections no. 1-4 (see Figure 3.10 for location of sample stations W1-W5).

South Slough Station:	Site W-1	Site W-2	Site W-3	Site W-4	Site W-5
Location:	Charleston Channel	Younker Pt.	Valino Is.	Ferrie Pt.	Hidden Creek
Estuary region:	euhaline	euhaline	euryhaline	euryhaline	mesohaline
Distance from mouth:	2.3 km	3.1 km	3.7 km	4.0 km	5.0 km
Sample depth:	1.2 m	3.0 m	1.0 m	1.2 m	1.0 m
Sediment type:	sandy mud	sand, shell, mud	sandy mud	mud	mud
% Volatile Solids:	2.1 %	1.1 %	2.0 %	1.2 %	8.0 %
% Water:	20.6 %	22.3 %	27.3 %	26.8 %	58.2 %
Taxon					
Foraminifera	-	3	5	-	-
P. Aschelminthes:					
C. Nematoda	653	20	3034	210	48
P. Nemertea:	13	-	-	11	3
P. Platyhelminthes:					
C. Turbellaria	3	1	6	1	-
P. Phoronida:					
Phoronopsis harmeri	49	-	-	12	-
P. Annelida:					
C. Oligochaeta	375	78	312	701	68
C. Polychaeta					
Abarenicola sp.	5	-	15	-	2
Capitella capitata	-	-	2	7	-
Chone ecaudata	-	-	1	-	-
Eteone californica	-	-	-	3	1
Fabricia sabella	-	-	-	-	861
Glycera tenuis	1	-	-	-	-
Glycinde armigera	1	1	2	2	-
Leitoscoloplos panamensis	-	2	-	-	-
Heteromastus filiformis	-	-	3	167	-
Ehlersia cornuta	-	4	-	-	-
Lumbrineris latreilli	8	-	-	-	-
Magelona pitelkai	-	2	-	-	-
Mediomastus acutus	2	-	25	12	2251
Mediomastus californiensis	38	1	16	24	-
Neomediomastus glabrus	-	-	1	3	-
Paraonella platybranchia	-	3	-	-	-
Polydora cornuta	-	-	-	-	1
Pygospio elegans	122	1	323	1	507
Rhynchospio glutaea	-	-	16	11	-
Streblospio benedicti	-	-	-	3	-
P. Mollusca:					
C. Bivalvia					
Clinocardium nuttallii	-	-	-	1	-
Macoma inquinata	-	1	3	11	-
Macoma nasuta	-	-	1	2	-

Table 3.6 Continued next page

Table 3.6 Continued

South Slough Station: Location:	Site W-1 Charleston Channel	Site W-2 Younker Pt.	Site W-3 Valino Is.	Site W-4 Ferrie Pt.	Site W-5 Hidden Creek
Estuary region:	euhaline	euhaline	euryhaline	euryhaline	mesohaline
Distance from mouth:	2.3 km	3.1 km	3.7 km	4.0 km	5.0 km
Sample depth:	1.2 m	3.0 m	1.0 m	1.2 m	1.0 m
Sediment type:	sandy mud	sand, shell, mud	sandy mud	mud	mud
% Volatile Solids:	2.1 %	1.1 %	2.0 %	1.2 %	8.0 %
% Water:	20.6 %	22.3 %	27.3 %	26.8 %	58.2 %
Macoma secta	-	2	-	-	-
Macoma sp.	-	-	-	1	-
Modiolus modiolus	9	12	-	4	-
Mya arenaria	1	-	-	1	4
Transennella tantilla	136	-	-	-	-
F. Tellinidae spp.	-	-	3	-	-
C. Gastropoda					
Melanochlamys diomedia	-	-	-	1	-
Tenellia adspersa	-	-	-	-	1
P. Arthropoda:					
C. Ostracoda	62	-	115	-	-
C. Copepoda					
Eurytemora sp.	-	-	1	-	-
O. Harpacticoida	134	5	24	13	2
C. Crustacea					
O. Cumacea					
Cumella vulgaris	138	1	15	1	3
Leucon subnasica	2	-	5	-	-
O. Tanaidacea					
Leptochelia dubia	1214	3	1897	1	2
Pancolus californiensis	-	-	-	-	1
O. Amphipoda spp.	-	-	1	-	-
Allorchestes angusta	-	-	4	-	-
Amphithoe valida	-	-	1	-	-
Corophium acherusicum	-	-	3	-	-
Corophium brevis	1	-	4	-	-
Rhepoxynius epistomus	-	4	-	-	-
Eobrolgus spinosus	123	6	287	3	-
O. Decapoda					
Crangon franciscorum	-	-	-	1	-
C. Insecta					
O. Collembola adult sp. A	-	-	-	1	-
O. Diptera					
Chironomida larva sp. A	-	-	-	-	6
Paraclunio alaskensis	-	-	-	-	7
Diptera larva spp.	-	-	-	-	15
C. Arachnida					
Halacaridae spp.	-	1	1	1	-
Pisces eggs spp.	87	3	318	15	-
TOTAL # INDIV:	**3177**	**154**	**6444**	**1225**	**3783**
TOTAL # TAXA:	**23**	**21**	**31**	**30**	**18**

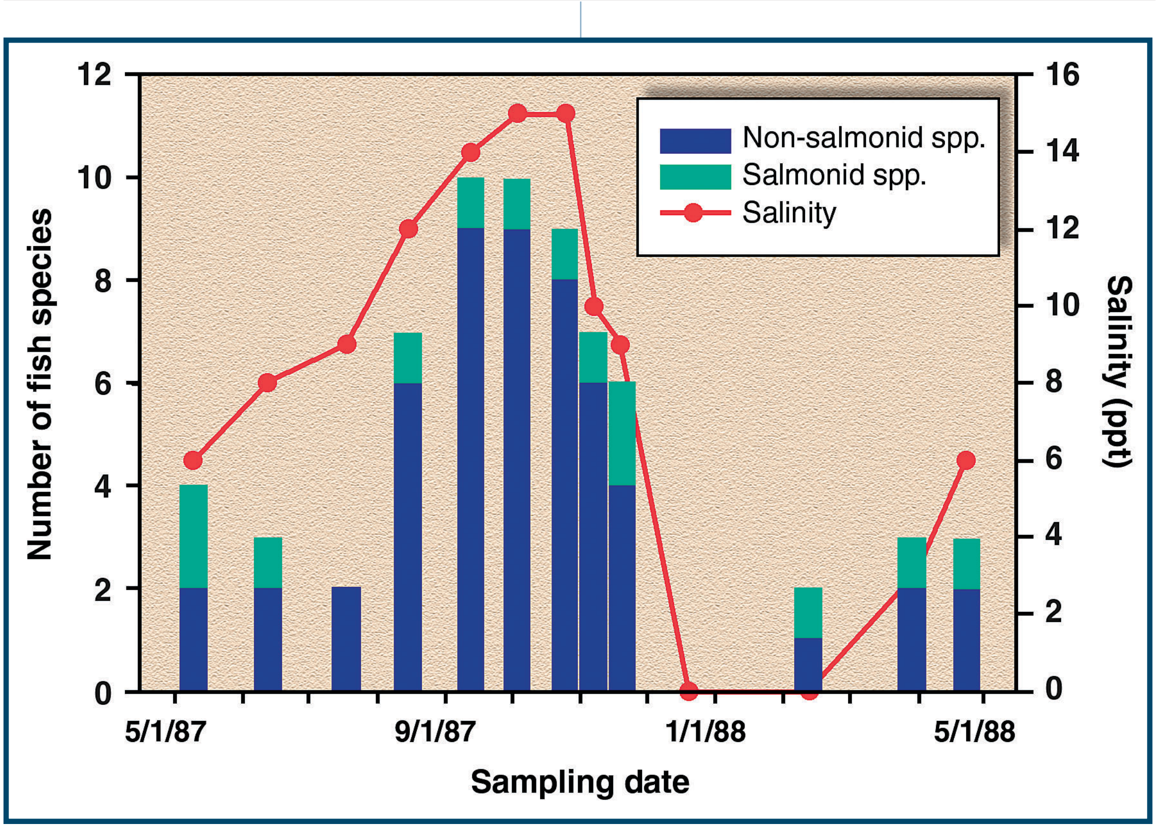


Figure 3.13. Relationship between date, ambient salinity, and number of fish species present in the Winchester Creek tidal channel, South Slough estuary, OR (May 1987-April 1988; adapted from Frank *et al.*, 1990).

infaunal invertebrate assemblages are probably due to fundamental differences in sediment characteristics including salinity, increased water and inorganic content, decreased grain size, and physical disturbance and removal of surface sediment layers (Jefferts, 1977).

3.3.3 Resident and Migratory Fish

Factors that influence the community composition and structure of estuarine fish in the riverine tidal channels of South Slough include freshwater inputs, physiological constraints, limitations on the availability of suitable habitats and prey items, and interspecific interactions between resident tidewater species and migratory fish (Frank *et al.,* 1990). Seasonal changes in ambient salinity strongly influence the number of fish species that occur in the Winchester Creek region of the South Slough (Figure 3.13). Species richness of fish communities in the narrow tidal channel is typically highest during September and October when surface salinities are in the range of 15-20 psu at low tide. Rainfall events in November mark the beginning of the winter season which is characterized by increased freshwater inputs, decreased salinity, and increased current velocities. Onset of these storm events is generally correlated with a gradual decline in the species of resident fish. The anadromous salmonids, however, migrate upstream through the riverine region of the South Slough during periods of heavy rainfall and freshwater discharge in November-December (winter run) and May (spring run).

3.3.3.a Fish Communities in the Winchester Creek Tidal Channel

Shiner perch (*Cymatogaster aggregata*) and staghorn sculpin (*Leptocottus armatus*) are typically the most abundant resident fish in the Winchester Creek region of the South Slough (Frank *et al.,* 1990; Sadro, 2000). Shiner perch occur in greatest abundance in spring and early summer, and their numbers decline substantially in the fall until they are virtually absent in winter (Figure 3.14). Most shiner perch are captured in seine nets drawn through eelgrass beds (*Zostera marina*) with the remainder divided nearly equally between log jams and old log pilings. Shiner perch are epifaunal grazers that prey primarily upon amphipods and other crustaceans (Shrode *et al.,* 1983). Staghorn sculpins also follow a seasonal pattern, although they increase steadily in abundance over the spring and reach their peak density in late summer (July-September; Figure 3.14). Staghorn sculpins are found predominantly in rubble habitat and among log jams and pilings, although they also occur consistently in eelgrass beds and open tideflat habitats where they prey upon burrowing shrimp and other fish (Posey, 1986). Staghorn sculpins decline in abundance from October-November, and they are virtually absent from the Winchester Creek channel in December-February. Size frequency data indicates that the population of shiner perch is dominated in the spring by adult fish with body lengths of 90-130 mm (Figure 3.15). Juvenile shiner perch appear in the estuarine tidal channels in June with body lengths of 30-50 mm, and they grow steadily over the summer until they merge with the modal group of adults in October. In contrast, the population of staghorn sculpins was dominated by juvenile fish (40-80 mm) in April (Figure 3.15). These juvenile sculpins grew steadily in length over the summer to reach their maximum size of 90-140 mm in October.

Other resident fish that commonly occur in the riverine tidal channels of the South Slough estuary include walleye surfperch, topsmelt, bay pipefish, starry flounder, threespine stickleback, and prickly sculpin (Table 3.7). Census activities conducted in 1987, 1990, 1995, and 2000 indicate that the fish communities found in the Winchester Creek tidal channel are remarkably similar over time. These resident assemblages include a mixture of species with northern / boreal affinities and species with biogeographic centers of distribution in the south (Monaco *et al.,* 1992). Fish communities from the South Slough estuary strongly resemble those reported for Coos Bay (ODFW, 1990) and other Pacific northwest estuaries (Mullen, 1977, 1978; Bottom and Forsberg, 1978; Bayer, 1981; Simenstad, 1983; Monaco *et al.,* 1990; Castillo, 2000). Species richness of eastern Pacific estuarine fish communities is generally high in large tidal basins such as the Coos estuary that have deep mouths and a fairly unrestricted connection with the nearshore ocean (Bottom and Jones, 1990; Monaco *et al.,* 1992). Variability in fish diversity along the South Slough estuarine gradient follows a similar pattern to that observed on a much larger spatial scale within the

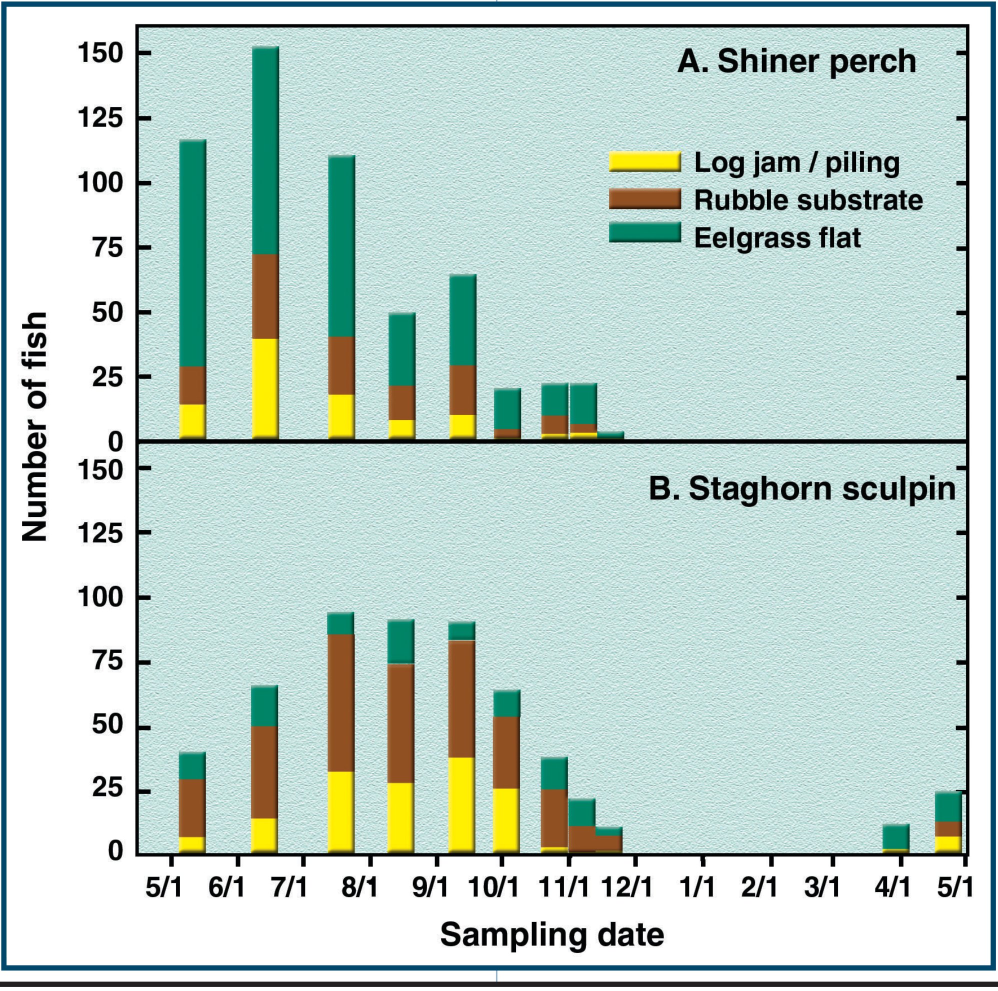


Figure 3.14. Seasonal abundance of: A) Shiner perch (*Cymatogaster aggregata*), and B) Staghorn sculpin (*Leptocottus armatus*) within the Winchester Creek tidal channel, South Slough estuary, OR (1987-1988; adapted from Frank *et al.*, 1990).

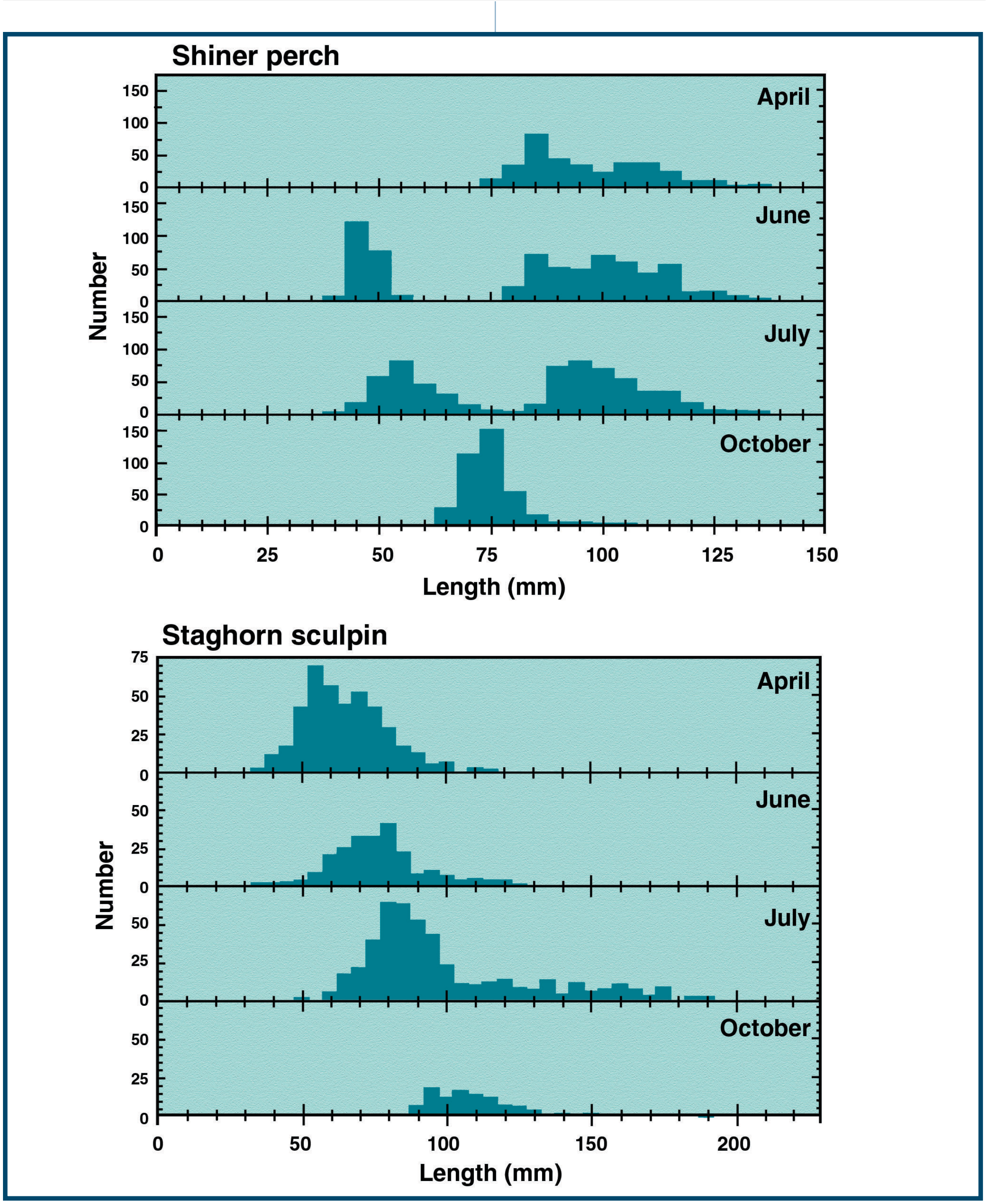


Figure 3.15. Size frequency distributions for Shiner perch (*Cymatogaster aggregata*), and Staghorn sculpin (*Leptocottus armatus*) within the South Slough estuary, OR (adapted from Bottom *et al*., 1988).

Columbia River estuary (NMFS, 1981). Communities of demersal or bottom fish reach their greatest diversity in the Columbia River estuary within the dynamic mixing zone (oligohaline and mesohaline region), while the diversity of open water (pelagic) species is greatest near the mouth of the estuary (Simenstad, 1983). The majority of fishes that occur in the middle and riverine regions of the South Slough estuary (*i.e.,* shiner perch, walleye surfperch, saddleback gunnel, bay pipefish, staghorn sculpin, prickly sculpin, English sole, and starry flounder) are considered demersal species that have strong associations with bottom sediments. These fish possess adaptations that allow them to live in conditions of variable salinity, high turbidity, low light, turbulent mixing, and unpredictable food resources that characterize the oligohaline and mesohaline riverine and middle regions of the South Slough.

Table 3.7. Fish communities collected during April-October in beach seines from the riverine region of Winchester Creek, South Slough (adapted from a. Bottom *et al.*, 1988 (site 5 only); b. Frank *et al.*, 1990, c. Rumrill and Scalici, 1996, and d. Sadro 2000). Note: sampling protocol differs among these studies so direct comparisons should be made with caution. A = abundant, P = present.

Family:	***Genus & species*** **(common name)**	**% of fish collected (year)**			
		1987^a	**1988^b**	**1995^c**	**2000^d**
Clupeidae:	*Sardinops sagax* (Pacific sardine)			5.6	0.2
Cottidae:	*Leptocottus armatus* (Staghorn sculpin)	A	45.5	61.1	41.9
	Cottus asper (Prickly sculpin)	P	1.3	4.4	1.6
Embotocidae:	*Cymatogaster aggregata* (Shiner surfperch)	A	44.7	9.6	22.8
	Hyperprosopon argentum (Walleye surfperch)	P	1.4		
	Phanerodon furcatus (White seaperch)	A			
Engraulidae:	*Engraulis mordax* (Northern anchovy)			0.2	
Gasterosteidae:	*Gasteroteus aculeatus* (Threespine stickleback)	P		17.3	17.7
Osmeridae:	*Atherinops affinis* (Topsmelt)	P	1.1	0.1	0.6
	Hypomesus pretiosus (Surf smelt)	P			
Pholidae:	*Pholis ornata* (Saddleback gunnel)	P		0.1	0.2
Pleuronectidae:	*Platichthys stellatus* (Starry flounder)		0.2	0.1	2.6
	Pleuronectes vetulus (English sole)	P			1.9
Salmonidae:	*Onchorhynchus kisutch* (Coho salmon)		2.0	0.4	1.3
	Onchorhynchus clarki (Coastal cutthroat trout)		3.1		2.7
Syngnathidae:	*Syngnathus leptorhynchus* (Bay pipefish)		0.6	1.1	6.5
	Total Fish Captured:	**NA**	**1,216**	**889**	**1,586**

Shallow estuarine channels, tidal creeks, littoral tideflats, and their adjacent salt marshes are known to provide nursery areas for postlarval and juvenile fish as well as forage areas for adults within the South Slough estuary (Bottom *et al.,* 1988; Frank *et al.,* 1990; Sadro, 2000). Fish communities sampled at high tide within salt marshes adjacent to Winchester Creek were dominated by highly mobile topsmelt and demersal staghorn sculpin (Table 3.8). Both of these species (as well as northern anchovy, striped bass, Pacific herring, threespine stickleback and others) migrate onto the tideflats and forage in the flooded salt marshes at high tide. During ebb tide, topsmelt exit the marshes and channel and migrate northward into deeper waters. In contrast, staghorn sculpin retreat only to the nearby tidal channel. Size frequency histograms for topsmelt populations indicate that large individuals continuously emigrate out of the South Slough estuarine system while smaller individuals immigrate into the system, presumably to forage and escape predation. Seasonal appearance of juvenile starry flounder and shiner perch in May and June provides further evidence that the South Slough functions as a feeding area and nursery refuge for these estuarine fish. The overall density and biomass of fish communities fluctuate both seasonally and annually within the tidal basin and most likely reflect temporal variability in the strength of fish populations and the availablity of prey resources.

Table 3.8. Species composition and biomass for fishes captured in the Winchester Creek tidal channel and adjacent experimental restoration marshes in 1998-99 within the riverine region of the South Slough estuary, OR (adapted from Sadro, 2000).

Species	Winchester Cr. Tidal Channel No. caught	%	Total Wet wt. (g)	Adjacent Marshes No. caught	%	Total Wet wt. g
Topsmelt	5	0.09	6.7	4726	68.6	14626.6
Pacific herring	1	0.02	0.4	7	0.10	6.6
Prickly sculpin	69	1.29	211.8	3	0.04	8.2
Shiner perch	69	1.29	1287.8			
Northern anchovy				71	1.03	60.5
Threespine stickleback	197	3.69	223.1	38	0.55	34.6
Staghorn sculpin	4890	91.64	8303.4	2029	29.47	2321.1
Striped bass				1	0.01	2096.8
Coho salmon	21	0.39	736.3	1	0.01	1395.2
Saddleback gunnel	1	0.02	8.1			
Starry flounder	40	0.75	499.1	3	0.04	57.5
Cutthroat trout	43	0.81	4389.7	4	0.06	208.2
Bay pipefish				1	0.01	2.0

3.3.3.b Use of the South Slough Estuary by Anadromous Salmonids

Estuaries throughout the Pacific northwest provide important rearing habitat for many stocks of anadromous salmonids (Reimers, 1973; Healy, 1982; Simenstad *et al.,* 1982; Simenstad, 1983; Nicholas and Hankin, 1988). Factors that control survival of salmonids in estuarine or nearshore marine environments are poorly understood, and the influence of interannual differences in nearshore ocean conditions on the abundance of returning adults has only recently been established (Bottom *et al.,* 1998). Several species of Pacific salmon and trout (coho, chinook, chum, steelhead and cutthroat trout) rely upon the South Slough estuary during portions of their life-histories (Bottom *et al.,* 1988; Frank *et al.,* 1990; Rumrill and Scalici, 1997; Miller and Sadro, 2003). Chinook (*Onchorhynchus tshawytscha*) and coho salmon (*O. kisutch*), coastal cutthroat trout (*O. clarki clarki*), and steelhead (*O. gairdneri*) typically pass through or reside in the estuarine tidal basin as smolts that migrate out to sea, and these anadromous fish return to the Coos estuary and South Slough as adults when they make their way back into streams to spawn.

Estuarine habitats located within the South Slough (tidal channels, mudflats, flooded salt marshes) are generally considered to provide three primary benefits for smolts including: (a) sites for successful foraging, (b) habitat for the critical physiological transition from fresh to salt water, and (c) a refuge from marine predators. Tidal channels, littoral tideflats, and salt marshes within the South Slough are highly productive ecotones located at the interface between freshwater and marine habitats, and salmonid smolts grow rapidly in size and biomass during the period of estuarine residence (Miller and Sadro, 2003). In some cases, juvenile coho and immature chinook salmon continue to inhabit the marine regions of estuarine channels on a sporadic basis throughout the year (Simenstad *et al.,* 1982).

Spawning sites for adult coho salmon occur in the South Slough watershed in Winchester and Vaughn Creeks, and coho fry emerge fom the streams during late winter (Frank *et al.,* 1990). Young coho salmon fry (< 60 mm) are known to inhabit estuarine tidal creeks during spring and summer shortly after they emigrate downstream from their freshwater rearing sites (Simenstad, 1983). Secondary and tertiary tidal creeks provide protected forage areas, and coho fry from tidal creeks typically contain

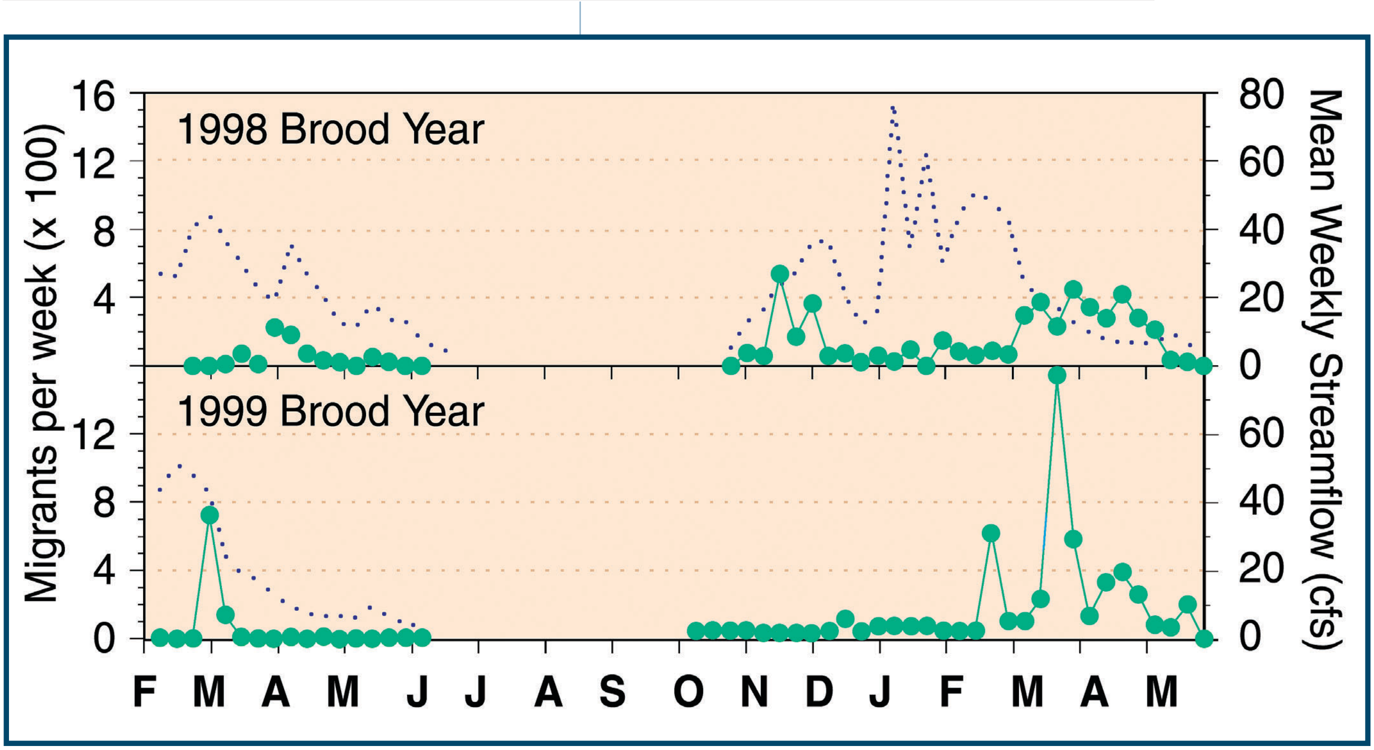


Figure 3.16. Migration timing for two broods of juvenile coho salmon within the Winchester Creek tidal channel, South Slough estuary, OR. Values indicate the number of migrant fish captured per week (X 100) at a tidal screw-trap. Dotted line shows mean weekly stream flow for Winchester Creek (cubic feet per second; cfs: adapted from Miller and Sadro, 2003).

higher numbers of prey items and rapid growth rates compared with fry reared in freshwater streams (Tschaplinski, 1988).

Coho fry observed in a newly created tidal creek (Dalton Creek marsh) in the South Slough estuary had growth rates of 0.44 mm day^{-1}, nearly double those of fry that reared upstream in a freshwater creek (Miller and Sadro, 2003). After coho fry reach a length of 70-85 mm they migrate downstream into the primary Winchester Creek tidal channel. Initiation of the smoltification process is size dependent, and a subset of the coho fry population from the upper region of the South Slough drainage system was able to reach the size necessary for smoltification as sub-yearlings. Several coho fry were captured in the Winchester Creek tidal channel from April through June when salinities are typically in the range of 20-30 psu. It is likely that some precocious coho fry may exit the tidal creeks and channels of the South Slough estuary along with older (age 1+) coho smolts.

Residence patterns for outmigrating coho salmon and cutthroat trout smolts in the Winchester Creek drainage system vary substantially between and within species. Outmigration of smolts from both species typically occurs between February and May (Figure 3.16), and the peak of downstream migration corresponds directly with periods of heavy precipitation and high freshwater discharge. Information derived from dye-marked and ultrasonic-tagged fish suggests that some coho salmon smolts swim rapidly through the estuary regardless of tide and habitat conditions, while others reside in off-channel ponds and backwater wetlands, linger temporarily in the tidal currents or even reverse their downstream migration and re-enter freshwater streams. During the period of estuarine residence young coho salmon appear to forage in the tidal creeks and salt marshes on an opportunistic basis (Shreffler *et al.,* 1990; Miller and Simenstad, 1997).

The residence time for individual coho salmon varies widely (Dawley *et al.,* 1986) and has been conservatively estimated at 13-40 days for estuaries in Washington state (Simenstad, 1982). Life history patterns of juvenile coho salmon were investigated in the South Slough estuary (Winchester Creek tidal channel) by Miller and Sadro (2003). The migratory behavior of juvenile fish was followed for two consecutive broods, and residence times were determined for juvenile coho within the transitional area between Winchester Creek and the riverine region of the South Slough estuary. Nearly 50% of the juvenile coho migrants to the estuary were sub-yearlings (Table 3.9; Figure 3.16), and a strong relationship exists between the timing of outmigration and residence time in the upper region of the South Slough (Figure 3.17). A small portion of the age-0 spring migrants remained within Winchester Creek through summer (for a period up to eight months). In contrast, fall/winter coho migrants had mean residence times of 48-64 days, but 75% of the juvenile salmon remained in the transitional habitat for 12- 40 days and 25% remained for 50-84 days (Figure 3.17). Eight coho salmon smolts implanted with ultrasonic transmitters exited the upper region of the estuary, and four survived to emigrate from the South Slough. These four smolts remained in the lower estuary for an average of 5.8 days. Fish always moved in the same direction as the current and spent an average of 65% of their detected time holding their position. Results from these studies indicate that pre-smolt migrants to the South Slough estuary may form a significant proportion of the total juvenile coho salmon population, and that the upper riverine region of the estuary provides habitat for a period of extended rearing. They also suggest that coho salmon sub-yearlings may migrate to the ecotone between the freshwater streams and estuarine tidal waters, remain within the transitional habitat for months, migrate back upstream during fall to over-winter in streams, and then emigrate from the system as sub-yearling smolts.

Cutthroat trout also had relatively long residence times in the upper riverine region of the South Slough estuary. Individually tagged cutthroat parr (originally captured above the head of tide) were recaptured after a period of 45 days in the Winchester Creek tidal channel (Frank *et al.,* 1990), and one smolt had a residence time of about 52 days. Sadro (2000) observed that cutthroat trout smolts had an average residence time of 12-20 days (min. 1-2 d, max. 47-75 d) in the upper Winchester Creek tidal channel (smolt trap) and an even longer average residence time of 19-31 days (min. 1-2 d, max. 63-100 d) at the net-seine site further downstream. The majority of out-migrant cutthroat trout captured at a trap site in Winchester Creek were in the 120-159 mm size class, but substantial numbers of smaller fish (90-119 mm) also exit the stream system in the winter and early spring. Frank *et al.,* (1990) estimated the age of outmigrant cutthroat trout smolts to vary between 2 and 4 years, and they observed juvenile cutthroat trout in the

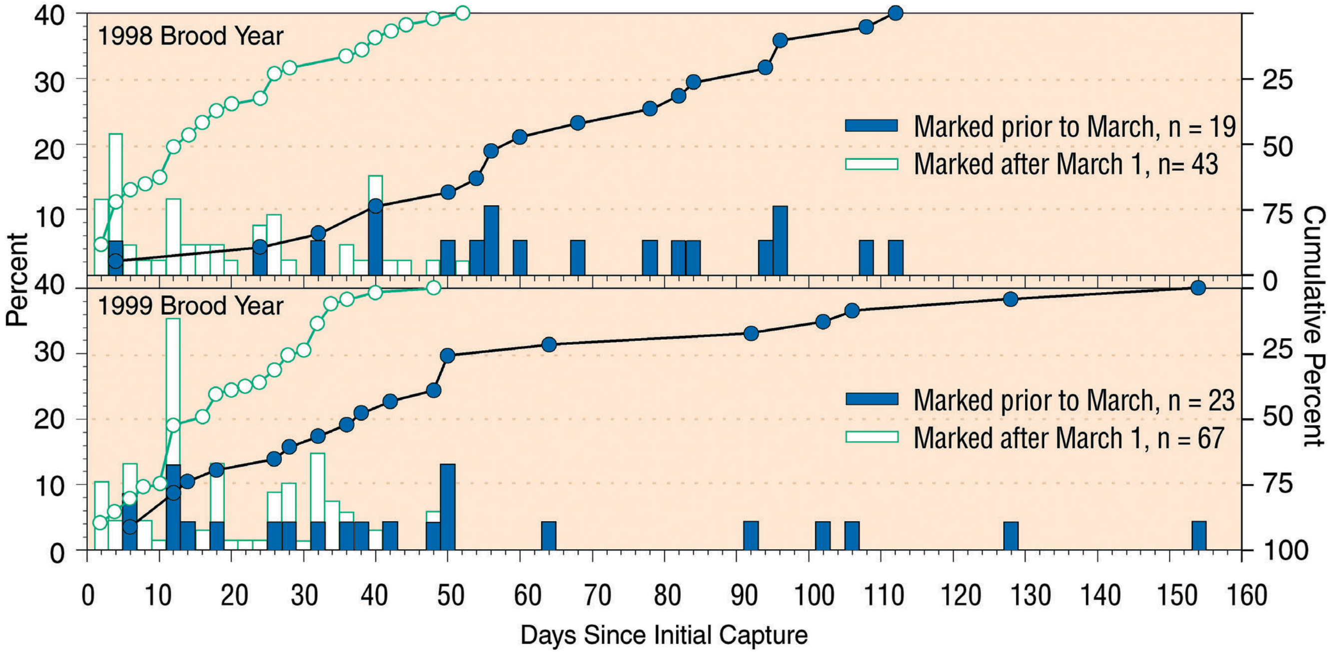


Figure 3.17. Minimum residence time of juvenile coho salmon in the freshwater stream / estuary ecotone (Winchester Creek region) of the South Slough, OR. Percent values indicate % of dye-marked juvenile fish that resided in the system for specific periods since initial capture. Cumulative Percent values indicate % of the juvenile fish population that reside for increasing lengths of time (adapted from Miller and Sadro, 2003).

Table 3.9. Estimated number of juvenile coho migrants that used the freshwater stream / estuary ecotone within the Winchester Creek region of the South Slough, OR. Low trap efficiency for age-0 coho salmon fry precluded calculation of variance; mean trap efficiency for all other migrants was used to estimate numbers of fry (adapted from Miller and Sadro, 2003).

Brood Year	Juvenile Coho Sample Period	Juvenile Coho Migrants (age)	Percent
1998	Feb – May 1999	680 (0)	13.2
	Nov 1999 – Feb 2000	1890 (0+)	34.1
	Mar – Jun 2000	2977 (1)	53.7
	Total = 5547 migrants		
1999	Mar – Jun 2000	893 (0)	14.0
	Oct 2000 – Feb 2001	1598 (0+)	25.0
	Mar – May 2001	3892 (1)	61.0
	Total = 6383 migrants		

Winchester Creek drainage system with ages of 0, 1, 2, and 3 years. Variability in the age of cutthroat trout outmigration in the South Slough is in agreement with estimates from other locations in the Pacific northwest (Fuss, 1982; Trotter, 1997). In some cases within the South Slough drainage system, it is not certain that the individual cutthrout trout are truly anadromous or members of resident freshwater stocks (Frank *et al.,* 1990). For example, a 4 yr old juvenile cutthroat trout with parr marks (no indication of smolting) was observed in Wasson Creek in mid May of 1988. If this individual were to emigrate through the South Slough estuary, it would exit in a novel life-history mode as a 5 yr old fish. By comparison, juvenile chinook salmon have a relatively short residence time of 4-6 days in specific salt marsh channels (Levy and Northcote, 1981) and residence periods of about 30 days for the entire drainage system of tidal creeks, subsidiary channels, and tideflats. Mortality rates for young salmon at sea are generally thought to be high, and the South Slough estuary probably plays an important ecological role by the provision of refuge habitats for the avoidance of predation by seabirds, marine mammals, and other fish.

The South Slough estuary also provides significant habitat for adult salmon (Bottom *et al.,* 1988). The migration rates for adult chinook and coho salmon, steelhead, and cutthroat trout often decline markedly in estuaries relative to the rapid movements of fish in nearshore marine areas. In addition, some chinook and coho salmon may require a second period of physiological adjustment prior to entry into freshwater streams and rivers (Simenstad, 1983). Maturing salmon sometimes cease feeding by the time that they reach estuaries, and they are probably exposed to relatively few predators outside of commercial and recreational fisherman and marine mammals. This information indicates that foraging opportunities and predation risk are probably minor factors compared with physiological adjustments in determining estuarine residence patterns for adult salmon in the tidal channels of the South Slough estuary.

3.4 Sandflat and Mudflat Habitats

Characteristics of sediment deposition and tidal hydrodynamics vary considerably along the longitudinal axis of the South Slough estuarine gradient. These physical forces interact with biogeochemical processes to create a spatial mosaic of different sandflat and mudflat habitats that are inhabited by distinct communities of estuarine organisms. In general, sandflats are more prevalent in the northern marine-dominated region of the South Slough, and mudflats occur throughout the estuary.

3.4.1 Benthic Microphyton Communities and the Redox Potential Discontinuity

Benthic microphyton communities (photosynthetic microalgae and diatoms) are ubiquitous and extensive within the surface layers of shallow tideflat sediments throughout the South Slough estuary.

Mats of blue-green algae (Cyanobacteria: *Lyngbya aestuarii*), yellow-green algae (Xanthophycea: *Vaucheria longicaulis*), and benthic diatoms exhibit patchy distribution patterns in the tideflats where they grow, retain moisture, trap sediments, and sometimes cause anoxic conditions in the underlying sediment. It has been estimated that the microphytobenthos can provide up to 50% of the carbon fixed in some coastal systems (Davis and McIntire 1983; Little, 2000) and they constitute the major portion of primary production and an important food resource for filter-feeders and deposit-feeders in the littoral tideflat habitats of Pacific northwest estuaries (Simenstad, 1983). Many benthic diatoms produce a mucilaginous film of extracellular polymeric substances (EPS) on the cell surface. The EPS layer can develop into a biogenic film that binds and traps fine sediments and organic detritus, increases sediment cohesion, and may hinder sediment resuspension in parts of the estuary. The layer of photosynthetic cells and their extracellular products can also form an organic barrier that decouples interstitial pore water from the overlying water column (Madsen *et al.,* 1993; Underwood and Paterson, 1993; Yallop *et al.,* 1994). Consequently, patchiness in the distribution and density of microphytobenthic communities can create micro-scale heterogeneity in subsurface oxygen conditions in the tideflat sediments. Important questions remain regarding the importance of microphyton assemblages in localized denitrification and facilitation of N_2 efflux from the South Slough estuarine system.

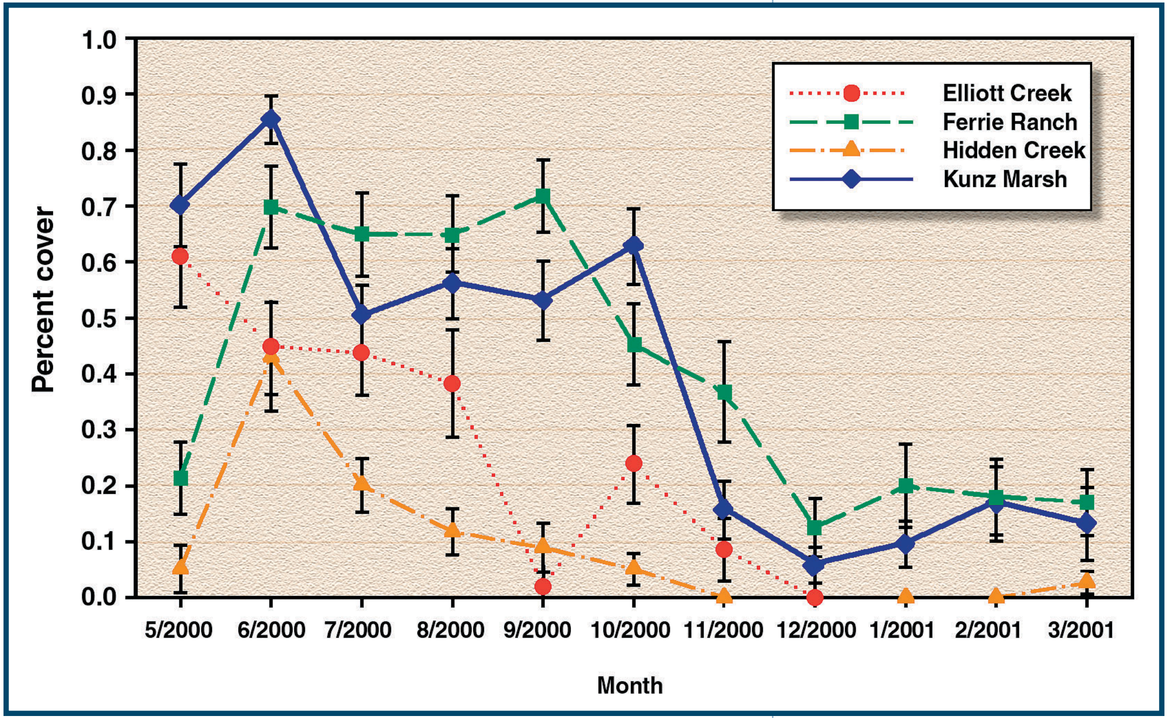


Figure 3.18. Spatial and temporal variability of yellow-green algal mats (*Vaucheria longicaulis*) in South Slough NERR, OR. The highest mean percent cover of *V. longicaulis* mats was found in Kunz marsh in June 2000. Ferrie Ranch and Hidden Creek also show peak mean percent cover in June 2000, while peak mean percent cover at Elliot Creek was in May 2000. A second peak occurs sometime between September and October at all sites except Hidden Creek. Error bars are the standard error calculated from monthly means at each site (from Milbrandt, 2002).

Benthic diatoms sometimes undergo diel vertical movements of several centimeters during daylight hours through the interstices of sediment particles. Motile diatoms typically migrate upward during low tide to reach the surface of the exposed sediments where they receive sufficient light to grow and reproduce. Whiting (1983) observed large mats of benthic diatoms on the surface sediments in eelgrass beds within Netarts Bay, OR. These mats are similar to the ephemeral and viscid biotic layers produced by the dominant benthic diatoms (*Melosira* spp., *Navicula* spp. and *Pleurosigma* spp.) in the central delta region of the Squamish River estuary, WA (Pomeroy and Stockner, 1976). The unstable benthic environment of estuarine tidal channel habitats may pose physical restrictions on the formation of mature microfloral assemblages. Notable exceptions may occur in protected locations where tidal scour is minimal such as within shallow blind lagoons or subsidary channels. Definitive descriptive information is lacking on the species composition and community structure of benthic microfloral assemblages in the estuarine tidal channels of the Pacific northwest (Simenstad, 1983).

Benthic mats of the yellow-green alga *Vaucheria longicaulis* exhibit strong seasonal and spatial variability in the upper intertidal zone of the South Slough estuary (Milbrandt, 2001). Greatest spatial cover was observed in June when the mats of dense coenocytic filaments can cover 70-85% of the available unvegetated surfaces (Figure 3.18). Spatial cover of *V. longicaulis* declines in July - September, and lowest spatial cover values occur in winter and early spring. The seasonal cycle of mat production is coincident with long photoperiod in summer and short photoperiod in winter. Mats of *V. longicaulis* persist as small isolated patches in the winter months. Spatial cover values for *V. longicaulis* were generally highest at the Kunz Marsh and Ferrie Ranch study sites, intermediate within the Elliott Creek tideflats, and lowest at the Hidden Creek site (Figure 3.18). Benthic mats of *V. longicaulis* and their associated communities of bacteria (*Anabaena* sp., *Oscillatoria* sp., *Microcoleus* sp.) appear to be important contributors to primary production in the estuarine tideflats of South Slough, particularly during the period between May and October (Milbrandt, 2001).

Benthic estuarine bacteria are an abundant and ecologically important element of the tideflat sediments of the South Slough (Minter 1982; Milbrandt, 2001). Sulfur-reducing bacteria (those that produce reduced sulfur compounds with energy released by the breakdown of organic matter) were ubiquitous in the tideflat sediments of the South Slough while sulfur-oxidizing bacteria (those that use reduced sulfur as an energy source) were absent (Minter, 1982). Sulfate reducers and cyanobacteria cultured from inoculated estuarine sediments include *Rhodopseudomonas, Chromatium, Thiobacillus,* and *Chlorobium.* These sulfur-cycle bacteria play a central role in the autotrophic production of organic matter within the tideflat sediments, and they also facilitate the decomposition of decaying material as well as provide a food source for meiofauna and infaunal invertebrates.

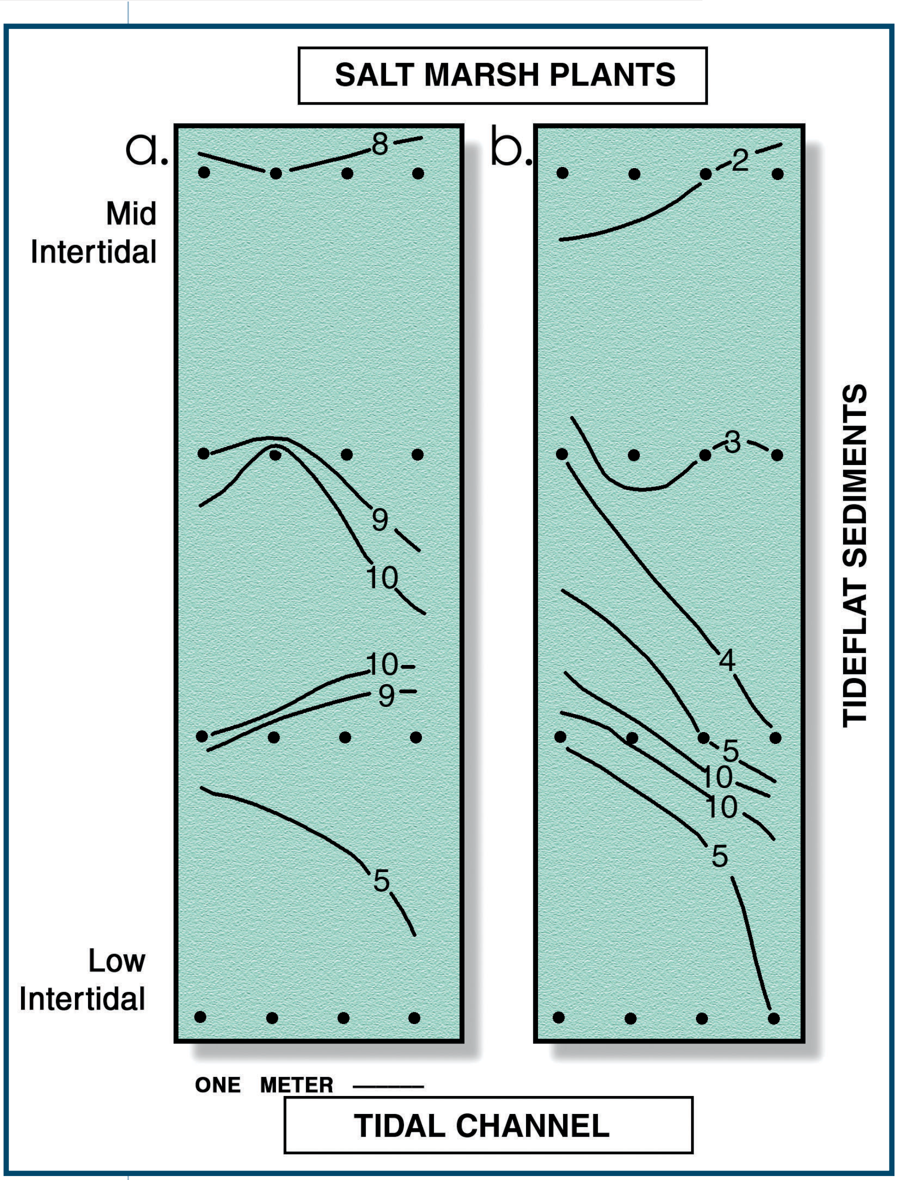


Figure 3.19. Contours of: a) chlorophyll and, b) phaeophytin concentrations in the upper 1.5 cm of sediment at South Slough (July 1981). The 4 m-wide strip sampled is perpendicular to the shoreline and the upper edge occurs at the boundary with salt marsh plants. A sand spit is located immediately outside of the sampling area to the right side of the diagram (adapted from Minter, 1982).

Milbrandt (2001) used 16S rDNA techniques to identify benthic bacterial communities within the tideflat sediments of the South Slough estuary. Composition of the bacterial communities did not vary significantly in the surface sediments on a small spatial scale (cm), but significant variability occurred at the scale of meters. Sediments from a relatively pristine site (Hidden Creek) were inhabited by a distinctive bacteria community compared with more disturbed sites at various locations around the estuary. In addition, the bacteria community

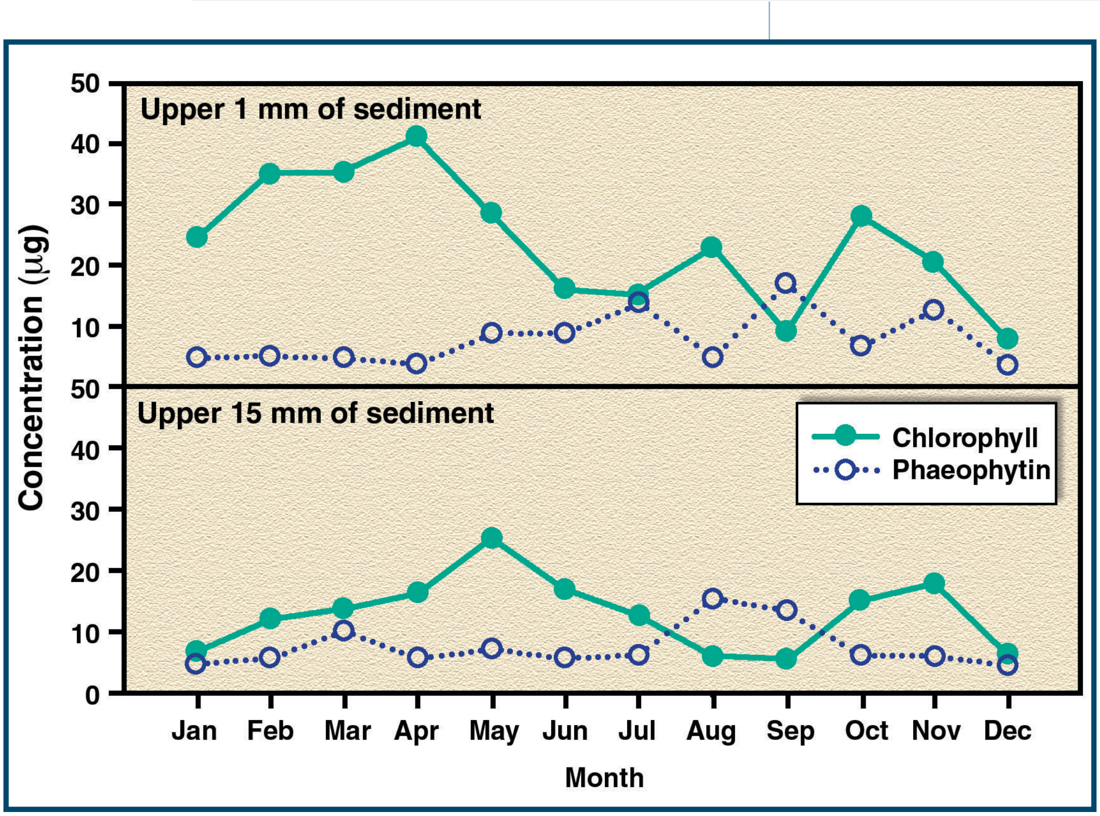


Figure 3.20. Seasonal variability in concentrations of chlorophyll and phaeophytin in the upper 1mm and 15mm of sediment within the South Slough estuary, OR (1981; adapted from Minter, 1982).

associated with mats of the yellow-green alga *Vaucheria longicaulis* differed substantially from bacteria communities sampled in open (non-mat) tideflats. Identification of estuarine bacteria by 16S rDNA techniques also revealed that distinctive bacterial communities occur at discrete depth strata within the tideflats at Hidden Creek. Bacteria identified from sediment depths of 0-1 and 1-2 cm formed a unified group, while bacteria from depths of 2-3 and 3-4 cm were distinctly different. The 16S rDNA technique also identified many taxa that are expected to live at the oxic–anoxic interface including *Pseudomonas fluorescens, Disulfobacterium catecholium, D. indolicum, Rhodobacter,* and *Proteobacterium* (Milbrandt, 2001).

Estuarine bacteria are responsible for many of the biochemical and physical characteristics of the tideflat sediments. For example, considerable variability exists in the chlorophyll and phaeophytin concentrations measured in the upper 1.5 cm of sediments across the intertidal gradient in the South Slough (Minter, 1982). These photopigments are derived from cyanobacteria, diatoms, and bacterial degradation of vascular plants. Minter (1982) measured photopigments in the intertidal sediments of the South Slough and found that both chlorophyll and phaeophytin concentrations were greatest at the mid intertidal level, about +1 m relative to Mean Lower Low Water (MLLW; Figure 3.19). Concentrations of these photopigments in surface sediments reflect accumulation and breakdown of endogenous and exogenous plant materials (Minter, 1982). Photopigment concentrations also vary considerably with sediment depth and over time. Sediment chlorophyll concentrations were greatest in the upper 1 mm strata, and exhibited elevated values in winter and spring months and generally lower values in the summer and fall (Figure 3.20). In contrast, sediment phaeophytin concentrations were greatest at a depth of 4 cm and they exhibited no seasonal pattern. Chlorophyll and phaeophytin showed a gradual decrease in concentration with depth, due to downward mixing from the photosynthetic surface layer followed by gradual decomposition of the pigments (Figure 3.21). Bioturbation by infaunal invertebrates is the primary mechanism for mixing of the tideflat sediments, and passage of sediments directly through the intestines of burrowing invertebrates could account for high subsurface phaeophytin concentrations (Minter, 1982).

Depth of the redox potential discontinuity (RPD) layer is an important physio-chemical boundary in the tideflat sediments of the South Slough estuary. The RPD layer is the depth within the unconsolidated sediments at which free oxygen disappears, and the diminished oxygen forms a distinct subsurface transition zone between aerobic and anerobic zones for decomposition of primary production (Fenchel and Riedl, 1970; Lenihan and Micheli, 2001). The RPD layer is generally 20-30 mm thick in the muddy tideflat habitats of the South Slough (Minter, 1982), but increases to over 50 mm in sandy substrata (Arkett, 1980). Depth of the RPD layer is dependent upon sediment grain size, porosity, availability of organic material, and diffusion of oxygen. Anoxic sediments occur below the RPD layer and are characterized by black sediment and the production of hydrogen sulfide and ferrous ions (*i.e.*, pyrite FeS_2). In some cases, iron sulfates and iron oxides are formed as precipitates around the roots of emergent plants (Ewing and Seebacher, 1997). In addition, oxygen transport along burrows, roots, and plant tissues (aerenchyma or lacunae) can dramatically alter redox potential (eH) values. For example, unvegetated mudflats within the South Slough estuary had a mean redox value of –83.92 at a depth of 5 cm while sites that were vegetated by small spike rush (*Eleocharis parvula*) were much higher (+58.25; Ewing and Seebacher, 1997).

Redox potential values varied seasonally between –3 and –157 mV at a depth of 5 cm within the unvegetated mudflats of the South Slough (Figure 3.22). Pearson and Rosenberg (1978) consider a depth of 30 mm to be a baseline RPD depth for a healthy marine-estuarine ecosystem. The RPD values of 20-30 mm to greater than 50 mm observed in the South Slough suggest that particular regions of the estuary may experience periodic ecosystem stress. Sediment temperature is an important variable when considering the process of bacterial consumption of organic carbon. Elevated temperatures induce rapid bacterial metabolism. Consequently, sediment pore water oxygen concentrations decline and the RPD becomes thinner. Assuming that any significant loss of pore water oxygen or organic carbon can be attributed to bacterial activity, it appears that an increase in temperature during the warm summer months could contribute substantially to seasonal difference in depth of the RPD layer. Spatial and temporal variability in the patterns of RPD depths indicates that long-term monitoring is needed to better understand the factors that control RPD variability and to ensure the continued health of the South Slough ecosystem.

3.4.2 Eelgrass Communities

Beds of native eelgrass (*Zostera marina*) constitute an important intertidal habitat in the South Slough estuary. Eelgrass beds contribute significant amounts of organic matter to the estuarine food web,

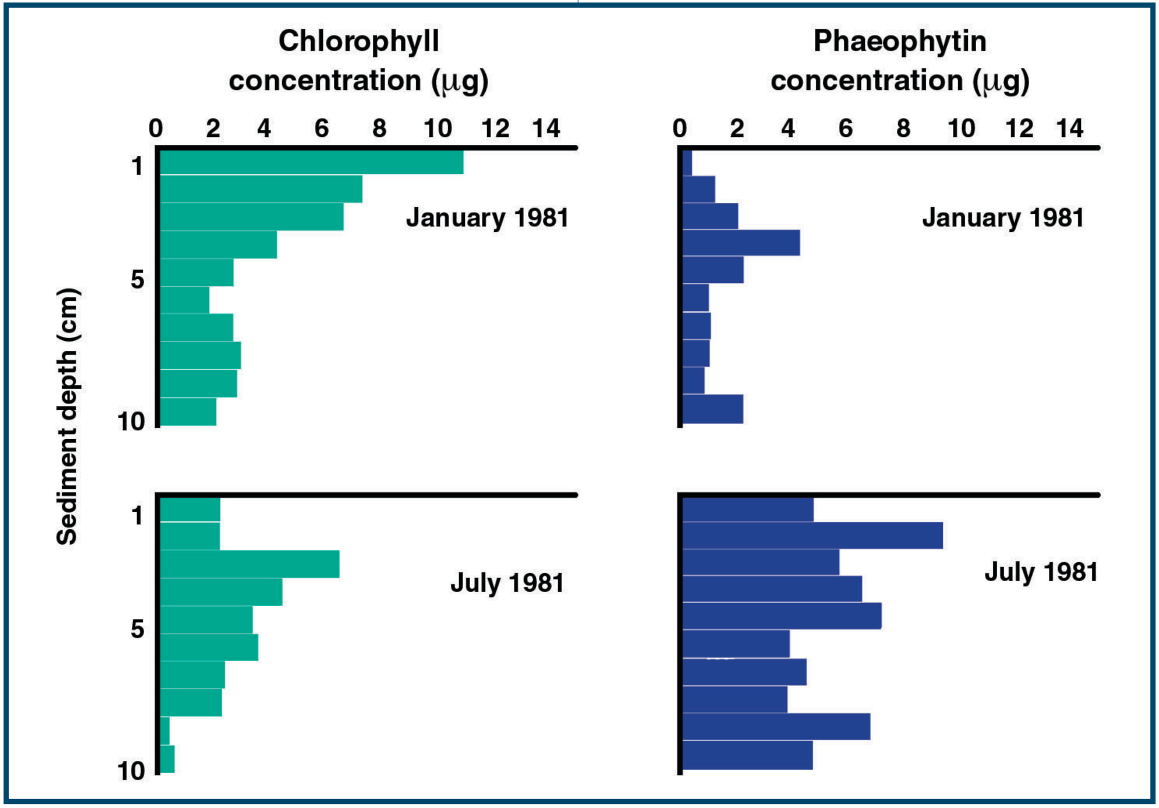


Figure 3.21. Depth-stratified concentrations of chlorophyll and phaeophytin within tideflat sediments, South Slough estuary, OR (adapted from Minter, 1982).

and they serve several additional ecological functions including sediment stabilization, nutrient processing, trapping of detritus, and the provision of shelter and forage habitat for motile invertebrates and fishes (Phillips, 1984). *Z. marina* is a flowering (angiosperm) plant that produces seeds during summer months and new roots and rhizomes during winter. As a strongly euryhaline species, beds of *Z. marina* can tolerate periodic immersion in freshwater at the mouths of Winchester and Talbot Creeks (in the riverine region of the South Slough estuary), but the eelgrass plants do not persist in fresh water. A salinity range of 10-30 ppt is optimal for growth of *Z. marina*, but seed germination is greatest at lower salinities (5-10 ppt; Phillips, 1972; Phillips *et al.*, 1983).

About 95 ha of *Z. marina* occur within the South Slough estuary, and about 44 ha occur within the South Slough National Estuarine Research Reserve. Eelgrass beds are expansive in the marine dominated region, particularly within the open tideflats at Barview Wayside, Brown's Cove, on the south side of Younker Point, and near Valino Island where they occur as patches or broad meadows in the open tideflats and as narrow fringe beds along the edge of the deep tidal channels (Figure 3.23). *Z. marina* had an average density of 160 plants m^{-2} (92% cover) at Barview Wayside and 112 plants m^{-2} (56% cover) at Valino Island in 2001 (Thom *et al.*, 2001). In contrast, the distribution of *Z. marina* is very patchy in the estuarine mixing zone where plants occur sporadically in 1-3 m^2 patches and smaller clusters of 3-6 plants along the edge of the tidal channel. Dense beds of *Z. marina* also occur in the riverine region of the South Slough where densities of 83 plants m^{-2} have been measured in the Winchester Creek tidal channel. Eelgrass blades are typically 1-2 m long and the canopy is suspended about 1 m above the substratum at high tide. The rhizomes of *Z. marina* generally extend 4-6 cm into the unconsolidated mud and sandy sediments, although they can penetrate much deeper in very soft mud. Growth rates of individual plants ranged from 0.4 to 1.1 cm day^{-1} near Valino Island in the South Slough. Individual leaves persist for 35 to 56 days in Netarts Bay, OR, and the plants produce 4-5 crops of

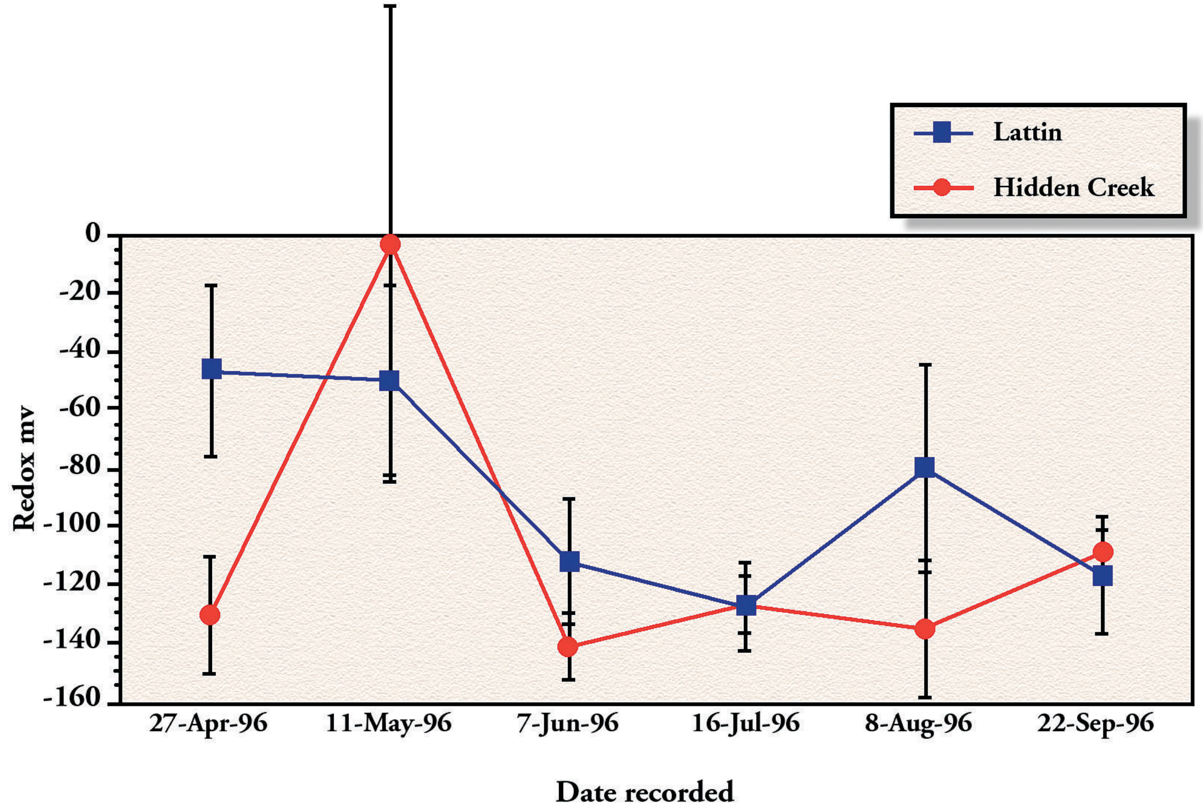


Figure 3.22. Seasonal variability in sediment redox potential values at Lattin and Hidden Creek marshes, South Slough NERR (April-September 1996; from Ewing and Seebacher, 1997).

leaves per year (Kentula, 1983). Eelgrass occurs within the +2 to –2 tidal range of mean lower low water in the South Slough, and it exerts an important influence on the sedimentary regime and distribution of infaunal and epibenthic organisms in the lowest intertidal zone.

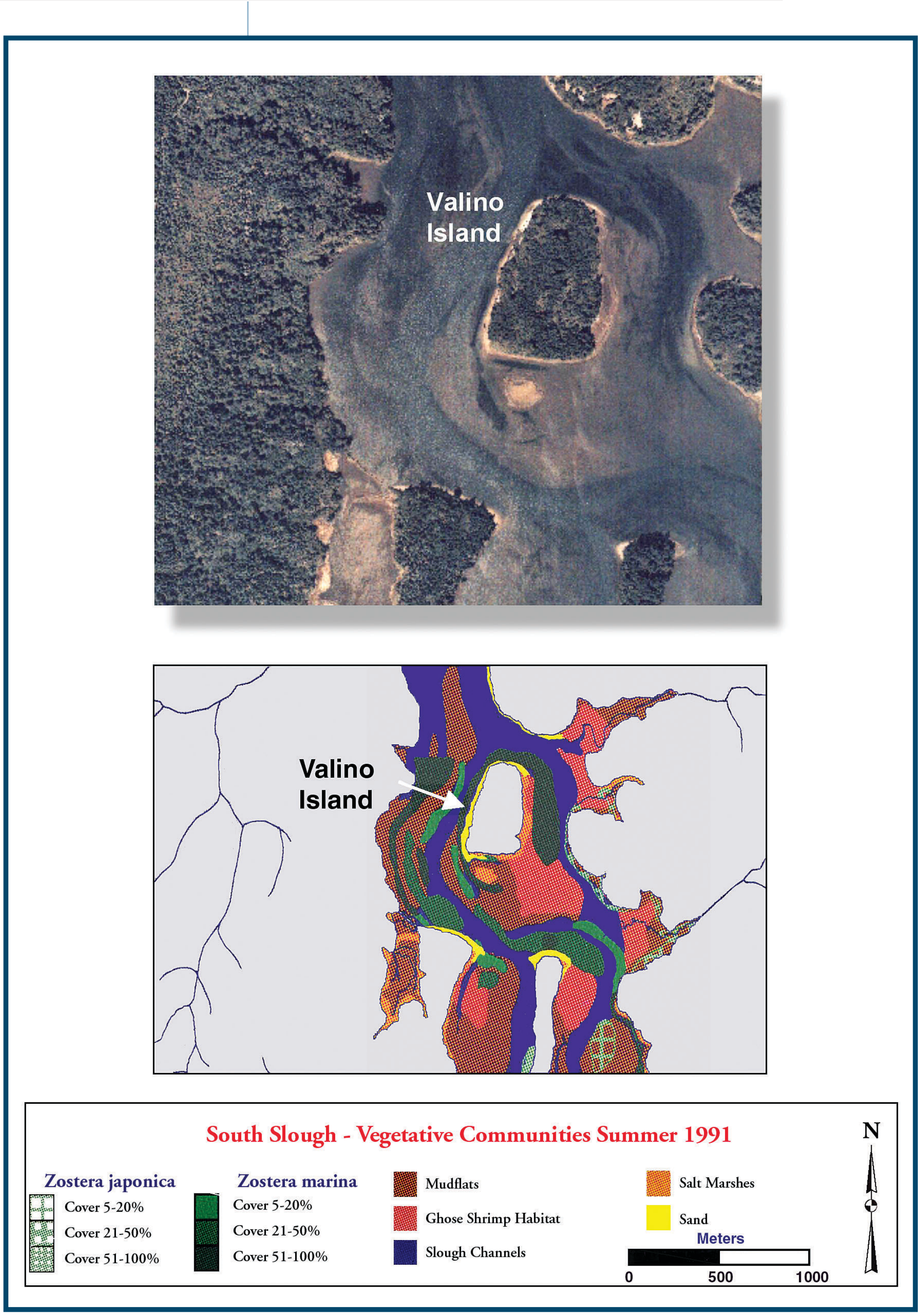


Figure 3.23. Aerial photograph and map of eelgrass beds (*Zostera marina*) in the mid region of the South Slough estuary, near Valino Island.

A wide variety of motile invertebrates and fish frequent the eelgrass beds within the South Slough estuary. Two species of crabs (*Cancer magister, C. productus*) are relatively common in dense eelgrass beds located near Valino Island (Figure 3.24), and the soft sediments beneath the orderly array of eelgrass shoots and blades is frequently inhabited by cockles (*Clinocardium nuttallii*), littleneck clams (*Protothaca staminea*), lugworms (*Abarenicola pacifica*), and many species of infaunal polychates. The bivalve molluscs may benefit from the dissolved organic carbon released from eelgrass blades, roots, and algal epiphytes (Phillips, 1984). In contrast, eelgrass beds located in the riverine region of the estuary are inhabited primarily by soft shell clams (*Mya arenaria*), amphipods (*Corophium* spp.), several polychaetes (*Capitella* spp., *Eteone, Manayunkia, Polydora*), staghorn sculpins (*Leptocottus armatus*), and shiner perch (*Cymatogaster aggregata*).

Eelgrass blades are elevated at high tide and form three-dimensional canopies that provide structure and complex habitat to the tideflats (Figure 3.24). Bay pipefish (*Sygnathus griseolineatus*) are common in the eelgrass canopies of the South Slough where they presumably forage and seek refuge from predation. Several species of crabs, various shrimps, amphipods, nemerteans, flatworms, snails, and flatfish occur in the eelgrass beds on an occasional basis. Harpacticoid copepods, nematodes, and oligochaetes are typically the most abundant organisms in eelgrass beds, but their densities have not been quantified in the South Slough estuary. Epibenthic harpacticoid

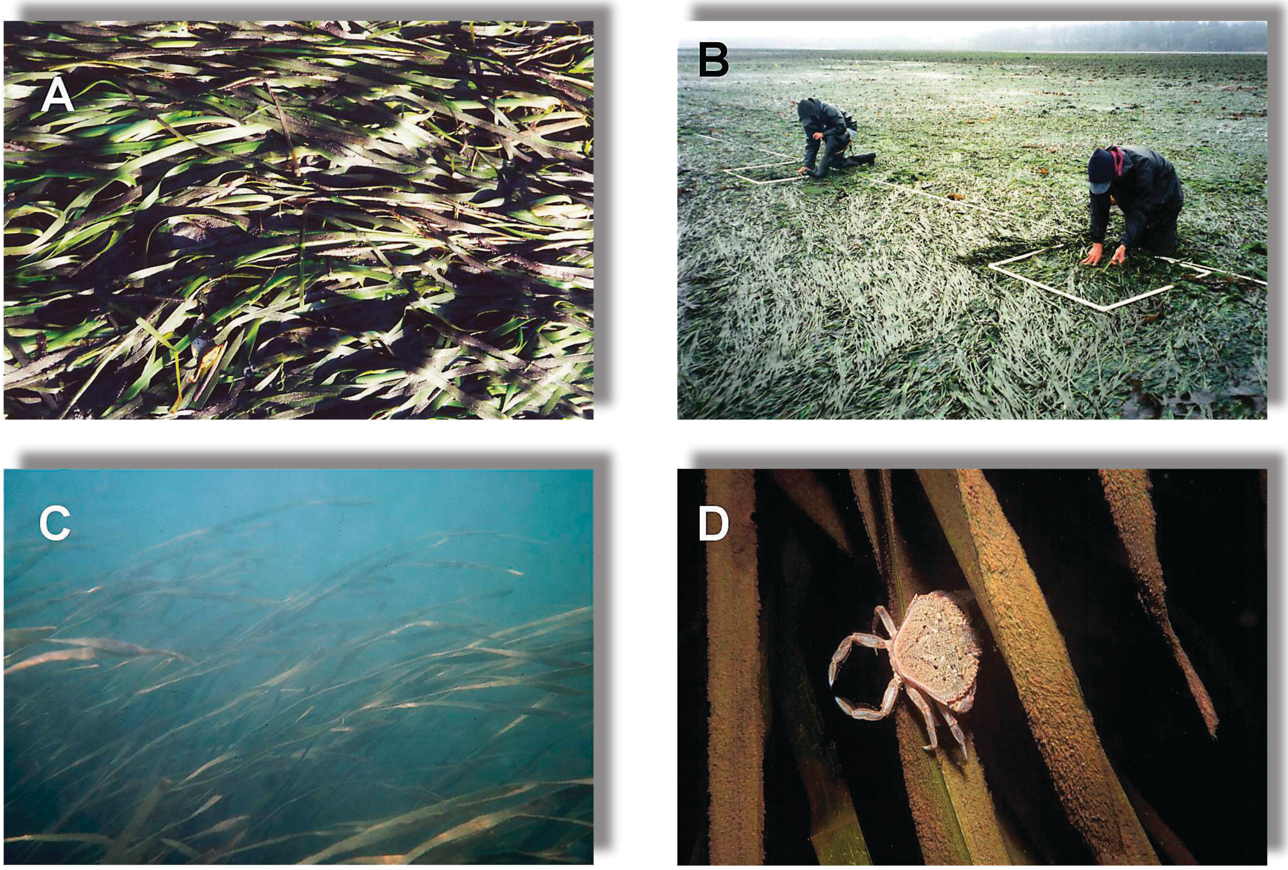


Figure 3.24. Eelgrass (*Zostera marina*) within the Coos estuary and South Slough NERR, OR. A. Dense beds of *Z. marina* are exposed on mudflats at low tide; B. Elongated eelgrass beds occur along the edges of primary tidal channels; C. Eelgrass canopy provides structure to the shallow subtidal zone; D. Juvenile Dungeness crab (*Cancer magister*) recruit and reside in the eelgrass canopy.

copepods (*Harpacticus* spp., *Tisbe* spp., *Zaus* spp.) and gammarid amphipods (*Corophium* spp., *Allorchestes* sp.) were the single most important food item consumed by several species of fish (chum salmon, Pacific sand lance, Pacific herring, surf smelt, threespine stickleback) in *Zostera marina* meadows in Padilla Bay, WA (Simenstad *et al.,* 1988). Definitive information is lacking to fully describe the assemblages of infaunal organisms that inhabit soft sediments in *Zostera marina* beds (Phillips, 1984). Although the infaunal invertebrate assemblage within eelgrass beds is generally more diverse in comparison to adjacent unvegetated areas, sediments in eelgrass beds do not usually contain unique assemblages of infaunal organisms.

The community of epiphytic organisms that grow upon blades of *Zostera marina* must adapt with severe time constraints on the availability of individual blades as a surface for community development. Sessile members of the epiphytic community (*i.e.,* red and green microalgae) are directly constrained by the longevity of individual blades, while motile epifauna can relocate to other blades. The food web associated with *Z. marina* blades is dependent on microphytic bacteria and diatoms, trapped detritus, and macrophytic algae attached directly to the blade. Many of the nursery and trophic functions of an eelgrass bed may not develop in the absence of a productive layer of epiphytes (Phillips, 1984).

Blades of *Zostera marina* provide an organic substratum for colonization by several different types of epiphytes and communities of epibenthic invertebrates. Epiphytic diatoms, algae, bacteria, and detritus that colonize *Z. marina* blades sometimes appear as a brownish coating, particularly in quiet water areas characterized by sediment deposition. Mutchler (1998) followed development of epiphytic diatom communities on eelgrass blades within the South Slough NERR throughout the 1996 growing season (Table 3.10). A total of 186 diatom taxa (species and varieties) were identified within the South Slough estuary (Shannon Diversity Index 3.98 to 4.32), and distinct communities of epiphytic diatoms occur along the estuarine gradient. The

Table 3.10. Summary of the mean relative abundance of common epiphytic diatoms collected from eelgrass blades in different regions of the South Slough estuary during the 1996 growing season. Estimates of relative abundance are indicated as P = Predominant (>20%), F = Frequent (5-20%), C = Common (1-5%), R = Rare (<1%), and A = Absent (0%); from Mutchler, 1998.

		South Slough Estuary Site		
Species code	**Diatom Taxon**	**Talbot Cr. (riverine)**	**Elliott Cr. (mesohaline)**	**Valino Is. (marine-dom.)**
Achnseve	Unid. *Achnanthes* sp.	C	R	R
Achntwel	Unid. *Achnanthes* sp.	A	A	A
Achricul	*Achnanthes ricula*	C	C	R
Achspone	Unid. *Achnanthes* sp.	R	R	A
Acofbore	*Amphora coffaeformis* var. *borealis*	C	R	R
Amphfour	Unid. *Amphora* sp.	C	R	R
Berkeone	*Berkeleya rutilans*	C	C	C
Cplaceug	*Cocconeis placentula* var. *euglypta*	P	F	C
Cpulchel	*Ctenophora pulchella*	C	R	A
Cscuparv	*Cocconeis scutellum* var. *parva*	C	R	C
Cscutell	*Cocconeis scutellum*	R	R	R
Fragexig	*Fragilaria exigua*	C	C	R
Frellipt	*Fragilaria elliptica*	C	C	C
Gexigua	*Gomphonemopsis exigua*	C	C	C
LinNavic	Unid. *Navicula* sp.	C	C	C
Melosone	Unid. *Melosira* sp.	C	R	R
Navduerr	*Navicula duerrenbergiana*	R	R	F
Navfiftn	Unid. *Navicula* sp.	A	R	C
Navicone	Unid. *Navicula* sp.	C	R	C
Navictwo	Unid. *Navicula* sp.	R	C	C
Navpermi	*Navicula perminuta*	C	C	F
Nitacicu	*Nitzschia acicularis*	R	F	C
Nitagnit	*Nitzschia agnita*	C	R	R
Nitangul	*Nitzschia angularis*	A	R	R
Nitdissi	*Nitzschia dissipata*	C	P	C
Nithrtwo	Unid. *Nitzschia* sp.	R	R	F
Nitpalea	*Nitzschia palea*	C	C	C
Nitsigma	*Nitzschia sigma*	C	C	A
Nitsocia	*Nitzschia socialis*	R	R	R
Nittwthr	Unid. *Nitzschia* sp.	R	R	R
Nitzfive	Unid. *Nitzschia* sp.	F	F	A
Nitzsvtn	Unid. *Nitzschia* sp.	C	C	C
Nitzthir	Unid. *Nitzschia* sp.	R	R	C
Pennasix	Unid. pennate diatom	A	R	R
Pennseve	Unid. pennate diatom	C	C	R
Sfascicu	*Synedra fasciculata*	C	F	P

marine-dominated region was inhabited primarily by *Synedra fasciculata, Navicula perminuta*, and *Nitzschia* spp., while the riverine region was characterized by *Cocconeis placentula, Ctenophora pulcella, Achnanthes* spp., *Amphora* spp., and *Nitzschia* spp. (Table 3.10). Epiphytic diatom communities in the middle – mesohaline region of the estuary exhibited intermediate characteristics. Densities of diatoms are greatest in the summer when they reach densities on the order of 1.6-3.8 million valves per cm^{-2}. Ordination analysis demonstrated that epiphytic diatom communities in the marine-dominated and mesohaline regions diverged substantially from communities in the riverine region over the growing season, particularly after the reduction of freshwater inputs in the summer (Figure 3.25). Epiphytic diatom communities develop and recover rapidly on the eelgrass blades; maximum cell densities are achieved after 7 days and disturbed diatom communities recover and were indistinguishable from

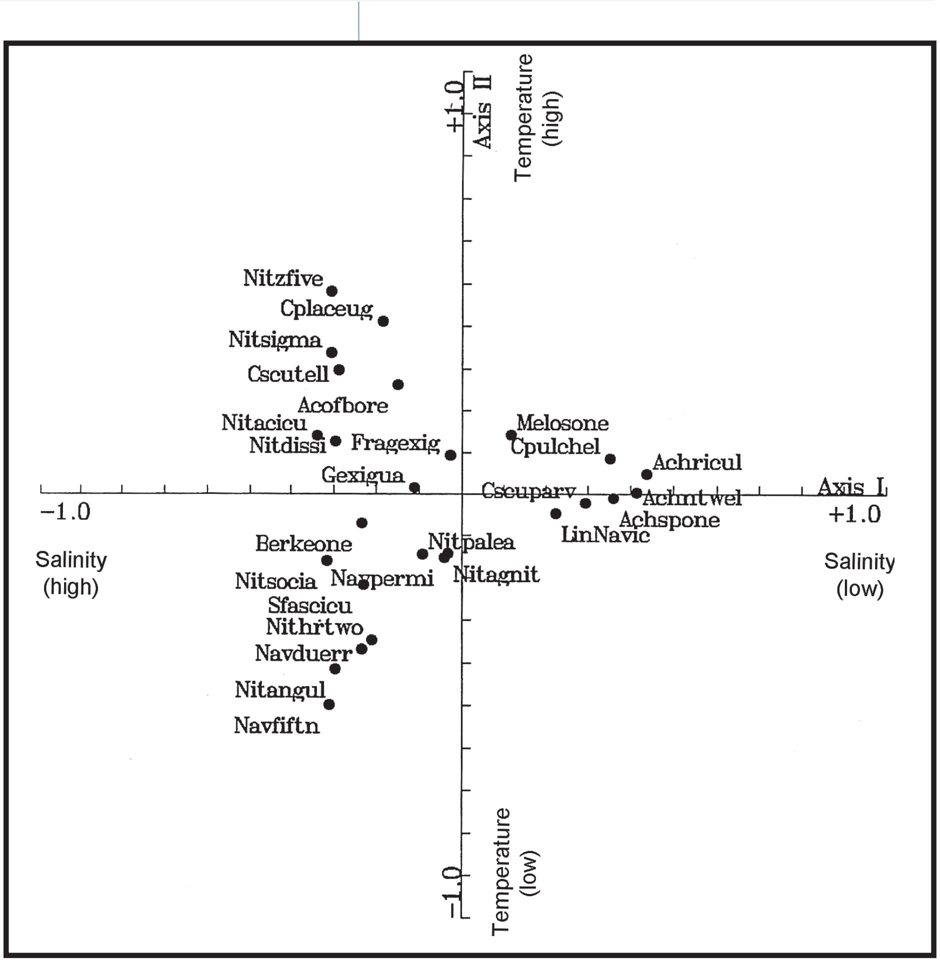


Figure 3.25. Correspondence analysis ordination plot for epiphytic diatom communities that grow on eelgrass blades within the South Slough estuary, OR. Axis I separates community members along the salinity gradient; axis II is strongly correlated with temperature, but also includes other covariates (depth, insolation, pH, dissolved oxygen; adapted from Mutchler, 1998). See Table 3.10 for identification of diatom taxa.

undisturbed communities after a period of 14 days. Factors that determine growth and distribution of epiphytic diatom communities include current velocities, nutrient loading, solar irradience, grazing, and salinity (Mutchler, 1998).

3.4.3 Macrobenthic Algae and Seaweed Communities

Several species of macrobenthic algae are abundant in the intertidal sandflats and mudflat habitats of the South Slough estuary. The standing crop of green algae is greatest in the summer months, and algal mats tend to accumulate at mid to high intertidal elevations (Figure 3.26). Green algae composed primarily of the flattened transluscent blades of *Ulva* spp. and the filamentous tangle of *Enteromorpha prolifera* and *E. clathrata* (Chlorophycophyta, Ulvales) are particularly conspicuous during summer months where they contribute significant spatial cover and biomass to the tideflat community (Figure 3.27). Extensive growth of *Ulva* and *Enteromorpha* in the spring and summer is most likely associated with increased photoperiod and warming of the intertidal flats (Pregnall, 1983; Hodder, 1986). Rapid growth of these species may also be stimulated by the seasonal influx of nutrients from the nearshore ocean during upwelling events (April-September). Production by *Ulva* and *Enteromorpha* within the northern region of the South Slough was estimated at 2,650 g dry wt m^{-2} over the 1982 growing season, and submerged photosynthesis accounted for 95% of total production (Pregnall, 1983). Net carbon fixation for *E. prolifera* averaged 7.37 mg C g dry wt^{-1} hr^{-1} in the light (30 ppt).

Interannual variability in green algal production is substantial. For example, the productivity rate for *Ulva* spp. was 798 g dry wt m^{-2} in 1983 and nearly twice as high (1,560 g dry wt m^{-2}) in 1984 in the estuarine waters of Coos Bay (Hodder, 1986). *Ulva* spp. was a conspicuous member of the estuarine tideflat communities in the early 1940's (Sanborn and Doty, 1944) and in the mid 1980's (Pregnall, 1983; Hodder, 1986). *Ulva* spp. were equally conspicuous throughout the South Slough during the period from 1990-2000, so it is likely that *Ulva* spp. is an established, seasonal, and persistent member of the intertidal communities rather than an opportunistic species whose abundance is strongly related only to

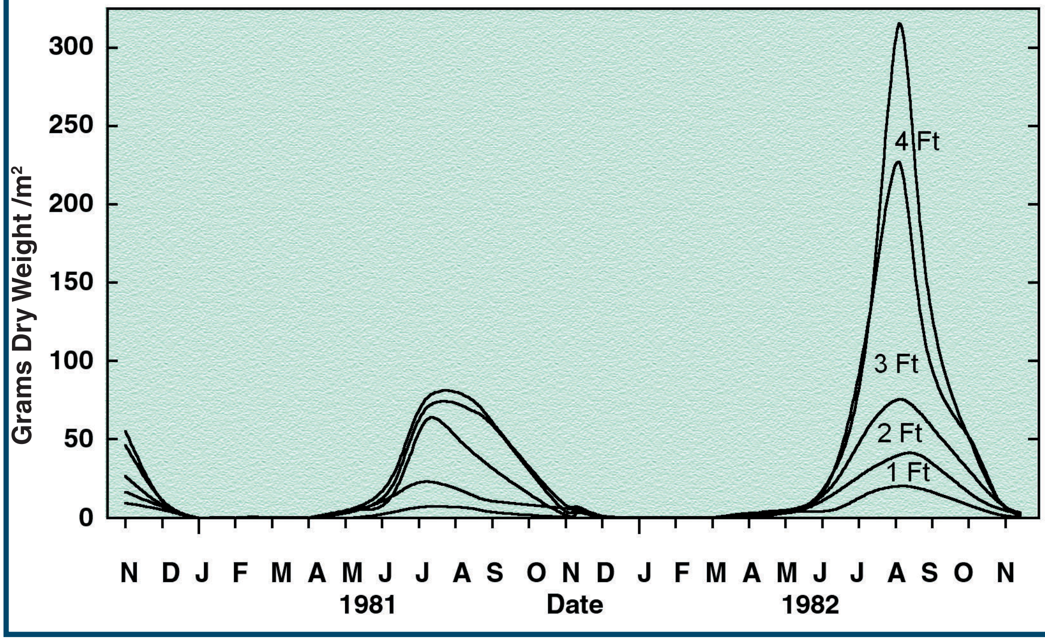


Figure 3.26. Annual pattern of green algal mat standing crop within the South Slough, OR. The uppermost line indicates mean value for the entire site, and the inner delineations represent relative contributions from five tidal elevations (+4, +3, +2, +1 ft above MLLW; adapted from Pregnall, 1983).

excess nutrients and non-point source pollution.

Tidal currents frequently lift the mats of *Enteromorpha* off the substratum and roll the filaments into long thick mucilagenous ropes. These algal ropes become aligned parallel with the advance of the tide in some portions of the tideflats where they accumulate other drifting materials and slowly decay. The thick mats and ropes of *Enteromorpha* contribute to anoxic conditions in the underlying sediments and to concomitant decreases in the abundance of infaunal and epifaunal invertebrates. During a field experiment conducted in the muddy tideflats of Königshafen (Island of Sylt, W. Germany) physical removal of *Enteromorpha* mats resulted in elevated numbers of invertebrates (particularly platyhelminths; Reise, 1985).

Tufts of the filamentous green alga *Chaetomorpha californica* form loose mats in sand and mud in the marine-dominated region of the South Slough near Valino Island. The tufts and filaments trap fine sediments and harbor diverse assemblages of amphipods, polychaetes, and cumaceans. Patches of the yellow-green alga *Vaucheria* sp. occur throughout the estuary as dark green spongy mats in intertidal areas that receive significant freshwater seepage or runoff. Like the mats of *Enteromorpha*, the thick filamentous

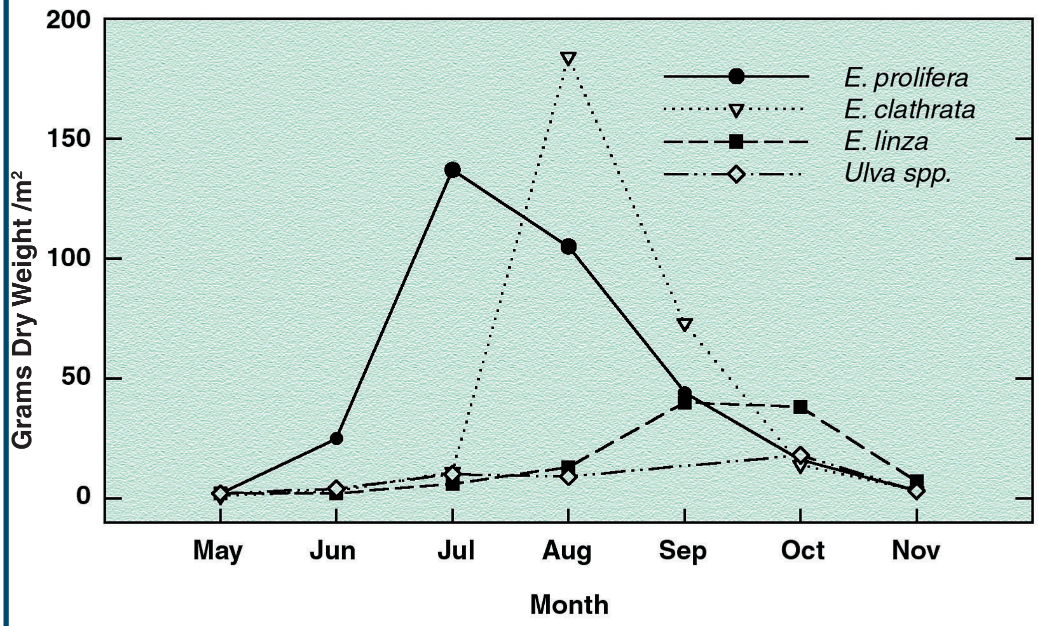


Figure 3.27. Changes in species composition of green algal mats sampled in the Sough Slough estuary during the growing season of 1982 (adapted from Pregnall, 1983).

mats of *Vaucheria* retain moisture and trap sediments. Early in the summer the *Vaucheria* mats provide shade and shelter for dense communities of diatoms, meiofauna, and epibenthic invertebrates. Later in the summer, however, the *Vaucheria* mats thicken and begin to decay, leading to anoxic conditions in the sediments below. Other species of macroalgae that occur in the intertidal flats include *Ulvaria fusca, Porphyra* spp., *Gigartina, Iridaea*, and *Desmarestia*. These benthic macroalgae are typically observed in the summer when they drift into the South Slough estuary on flood tides, become trapped in the eelgrass beds or algal mats, and continue to live on the muddy tideflats. Filamentous tufts of *Polysiphonia* sp. are commonly attached to bivalve shells and wood embedded in the mud, along with the very fine tangled filaments of *Rhizoclonium* sp. The tough greenish-brown dichotomous branches of *Fucus distichus* are also common, either attached to rocks, shell rubble, wood branches, logs, root wads, or as drift algae in the tideflats. Patches of fucoid algae also occur commonly as an understory species within the emergent vegetation of the salt marshes.

3.4.4 Meiofauna and Infaunal Invertebrates

Meiofaunal organisms and infaunal invertebrates are widespread and abundant within the soft sediment habitats of the South Slough estuary. The aequeous muds are conducive to the formation of temporary and permanent burrows, and the sediments are mixed with an ample supply of rich organic matter. Communities of meiofaunal organisms develop trophic relationships with living cells (bacteria and diatoms) and dead tissues within the sediments, and the detritus serves as a fundamental food source for diverse assemblages of infaunal deposit feeders. Invertebrate suspension feeders and mobile predatory species are also common functional group elements of the infaunal invertebrate assemblage.

Table 3.11. Composition, mobility mode, and depth distribution of major meiofaunal organisms collected from Valino Island, South Slough estuary, OR. Values shown are mean numbers of individuals / 10 cm^2 (adapted from Arkett, 1980).

Sediment Depth Strata	Meiofauna Taxa	Mobility Mode	Water Column Depth		
			0 cm	10 cm	25 cm
0-1 cm	Gastrotricha	Ciliary gliders	0	0	0
	Harpacticoida	Burrowers, crawlers	1	3	22
	Nematoda	Writhers	10	27	40
	Oligochaeta	Burrowers	1	1	1
	Turbellaria	Ciliary gliders	1	0	0
		Subtotals:	**13**	**31**	**63**
1-2 cm	Gastrotricha		0	7	1
	Harpacticoida		1	23	20
	Nematoda		49	40	64
	Oligochaeta		1	1	0
	Turbellaria		0	1	1
		Subtotals:	**51**	**72**	**86**
3-4 cm	Gastrotricha		4	7	10
	Harpacticoida		1	8	13
	Nematoda		63	32	25
	Oligochaeta		1	1	1
	Turbellaria		1	1	1
		Subtotals:	**70**	**49**	**50**
		Totals:	**134**	**152**	**199**

3.4.4.a Meiofaunal Communities

Sandy beaches within the South Slough estuary support diverse meiobenthos or meiofaunal communities composed of organisms that inhabit the interstices of the porous sediment. In his investigation of meiofauna from the intertidal sandy substrata along the South Slough estuarine gradient, Arkett (1980) adopted McIntyre's (1969) definition of the meiofauna as small metazoans that generally pass through 1 mm - 0.5 mm mesh screen and are separated from the larger macrobenthos by their size, numbers, functional morphology, elaborate life cycles, specialized reproductive behaviors, migratory patterns, mobility modes, and other adaptations. Meiofaunal communities within the South Slough are numerically dominated by nematodes, and also include large numbers of harpacticoid copepods, gastrotrichs, oligochaetes, turbellarians, ostracods, rotifers, tardigrades, and polychaetes (Figure 3.28; Table 3.11). Meiofaunal organisms typically occur in the upper 2 cm of surface sediments in densities on the order of millions m^{-2}, and their spatial distribution is heterogeneous due to local differences in particle grain size, interstitial pore size, water content, oxygen levels, food availability, predators, and other environmental factors (Higgins and Thiel, 1988).

The composition and abundance of meiofaunal communities are highly variable in at least three spatial dimensions within the sandy beach habitats of the South Slough (Arkett, 1980). First, the major groups of meiofaunal organisms varied considerably along the north-south estuarine gradient (Figure 3.29). Meiofaunal communities at Younker Point were dominated by harpacticoid copepods, while the Valino Island community was composed largely of a mixture of nematodes and harpacticoids and the Ferrei Head assemblage was dominated by nematodes. The group of meiofaunal organisms studied by Arkett (1980) were in greatest abundance at Younker Point (110,000 m^{-2}), intermediate at Valino Island (79,000 m^{-2}) and lowest at Ferrie Head (65,000 m^{-2}). Total numbers of meiofaunal organisms are much greater at these intertidal sites. The relative abundance of gastrotrichs, harpacticoids, and oligochaetes was directly correlated with the successive decrease in mean sediment grain size (Younker Point: 313.04 µm, Valino Island: 282.07 µm, Ferrei Head: 279.03 µm). Decreased density of meiofaunal organisms along the estuarine gradient may be related to the reduction in sediment grain size and higher coefficients of sediment sorting. Both of these parameters probably function to inhibit motility in organisms that exhibit ciliary gliding or crawling methods for locomotion (*i.e.,* gastrotrichs and harpacticoids). In contrast, the nematodes are well adapted to sediments with smaller pore spaces as their locomotory method requires tight interstices for leverage (see Table 3.11).

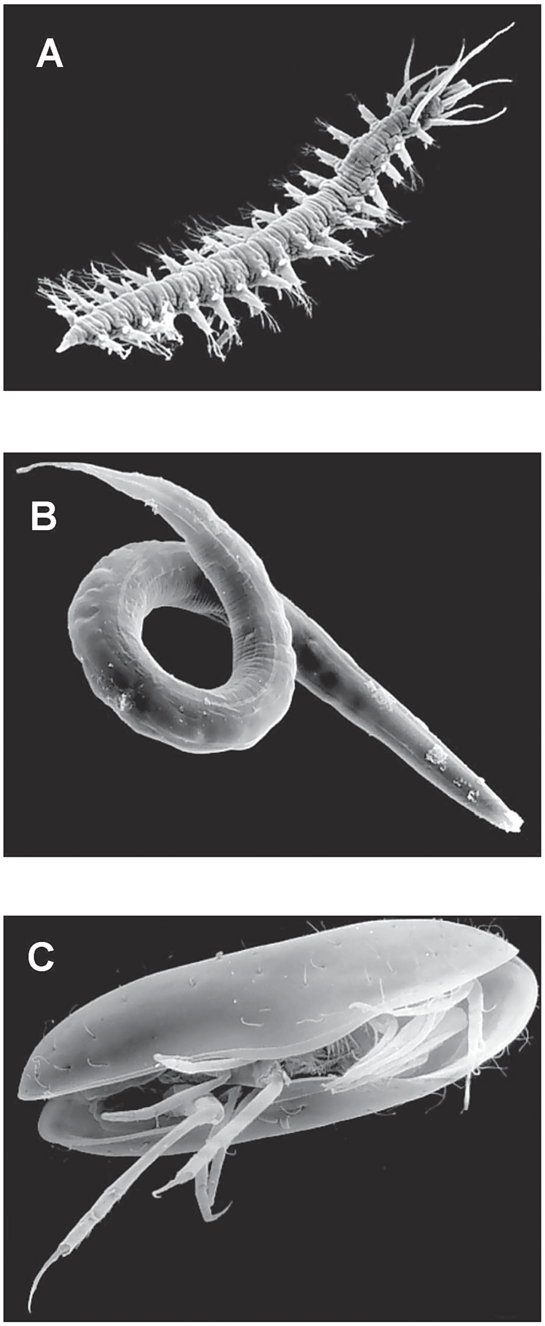


Figure 3.28. Examples of meiofaunal organisms from sandy substrata within Pacific northwest estuaries. A. Syllid polychaete: *Eusyllis* sp.; B. Marine nematode; C. Ostracod crustacean. Scanning electron micrographs of interstitial meiofauna from northern California by M. Hooge, 1999.

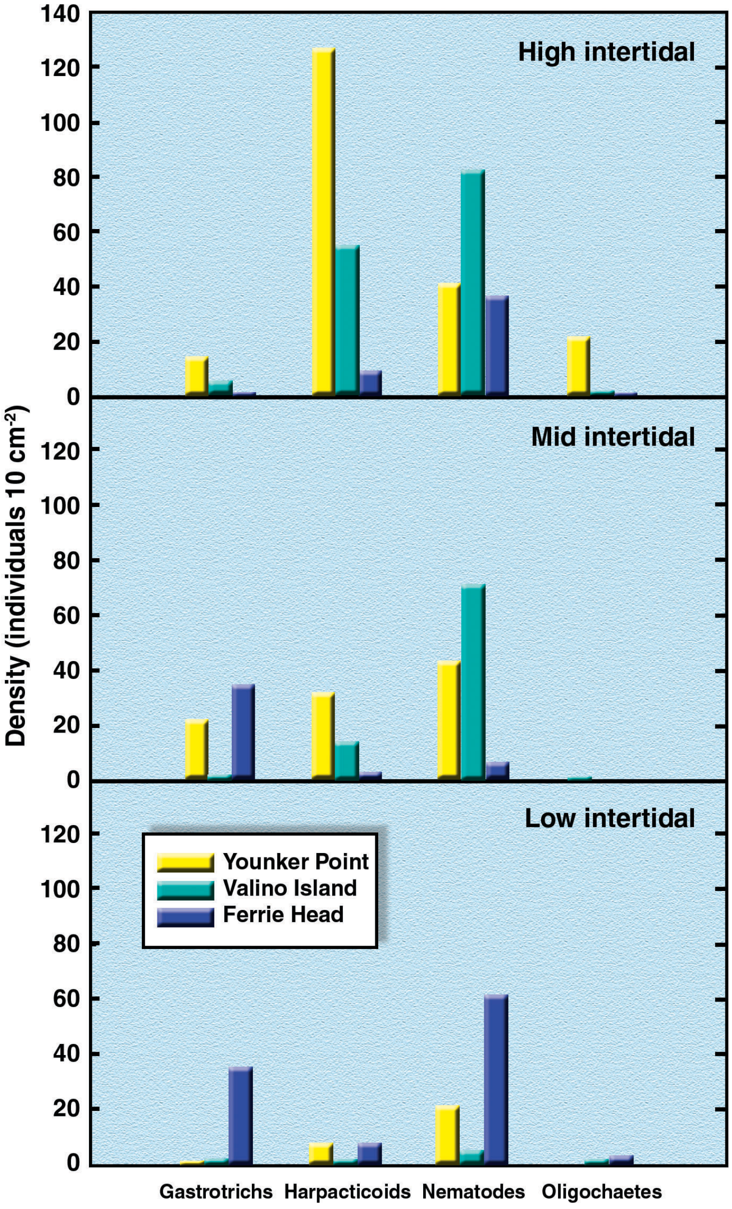


Figure 3.29. Spatial pattern in the composition and abundance of major meiofaunal organisms along the South Slough estuarine gradient, OR (adapted from Arkett, 1980).

Meiofaunal assemblages within the South Slough estuary also varied substantially with differences in intertidal elevation (Arkett, 1980). For example, harpacticoid copepods and nematodes were the most abundant meiofaunal organisms in the high intertidal zone, and gastrotrichs were abundant in the mid intertidal zone (Figure 3.29). The low intertidal zone was dominated by nematodes, although gastrotrichs were abundant at the Ferrie Head beach site. Oligochaetes were present at low densities at all intertidal zones (Figure 3.29). The composition and abundance of meiofaunal assemblages also varied substantially with sediment depth (Figure 3.30). Gastrotrichs, harpacticoids, and nematodes were most abundant at a sediment depth of 1-2 cm below the surface (Arkett, 1980), while organismal densities were intermediate at a sediment depth of 3-4 cm and lowest near the surface (0-1 cm). Low numbers of meiofaunal organisms found at the 0-1 cm depth strata probably reflects an escape response or avoidance of turbulence in the overlying water column (Arkett, 1980).

Meiofaunal communities also exhibited short-term vertical movements within the sandy tideflat habitats of the South Slough that were directly related to the rise and fall of the semi-diurnal tides. For example, significant increases in the total number of meiofaunal organisms occurred in the surface sediment after 1 hr of immersion (Arkett, 1980). Densities of meiofauna subsequently decreased in sediments after 2 hr of exposure to air. Meiofauna are known to move vertically through sandy sediments in response to alternate drying and wetting during the tidal cycle (Boaden and Platt, 1971; McLachlan *et al.,* 1977). The time scale of vertical movements observed within the South Slough, however, suggests that migration may be correlated with additional factors such as changes in the depth of the redox discontinuity layer, O_2, CO_2, and pH levels, interstitial water content, sediment temperature, and/or other parameters that vary over tidal, daily, or seasonal cycles. In some sandy beach habitats the redox discontinuity layer may be more than 1 m below the surface, and nematodes and harpacticoid copepods move upward within the sand as the tide rises and then descend 10 cm or more as the sand dries out (Hooge, 1999).

Meiofaunal organisms that inhabit the South Slough estuary generally feed on detritus, diatoms and bacteria, and they probably play an important role in making detritus available to larger predators (either by becoming prey or by increasing the activity of microbes). Intertidal and shallow water meiofauna populations probably vary substantially in size, composition, and distribution on a seasonal basis, and are expected to reach maximum abundance in the summer months. Interactions between meiofauna and other biological and chemical

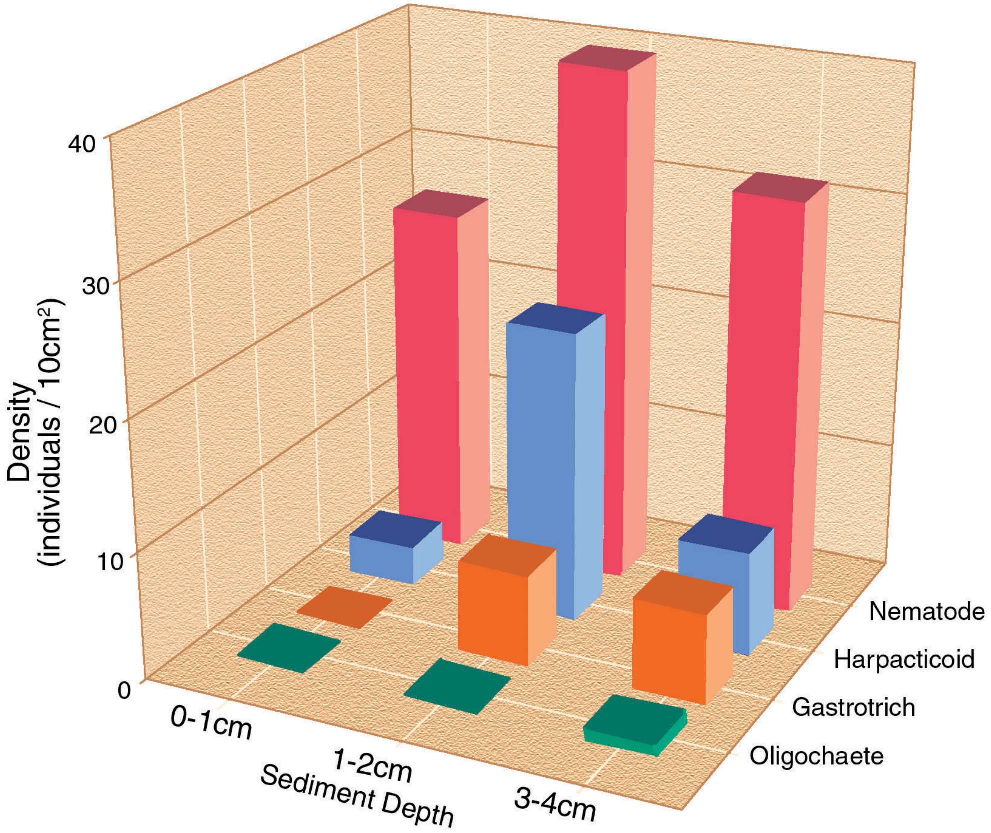


Figure 3.30. Depth distribution of major meiofaunal organisms at Valino Island, South Slough estuary, OR (adapted from Arkett, 1980).

components of the sediment system have not been investigated in the South Slough estuary. Moreover, important questions remain regarding the effects of environmental perturbations on the composition, abundance, and distribution of meiofaunal assemblages in the South Slough estuary. These characteristics of meiofaunal communities may respond directly or indirectly to variability in sediment conditions, food types (*i.e.,* diatoms), disturbance events (bioturbation and accumulation of detached macroalgae), increased inorganic nutrients, and the abundance of epibenthic predators (particularly shrimp and fish).

Mudflat habitats of the South Slough estuary also harbor abundant meiofauna. Although they have not been well studied, the fine-grained muddy tideflats within the middle and riverine regions of the estuary contain high numbers of nematodes, oligochaetes, harpacticoid copepods, and turbellarians. In general, the taxonomic diversity of meiobenthic invertebrates typically decreases in muddy habitats along with a decline in pore water salinity. Further reduction in the number of meiofaunal organisms along the estuarine gradient is related to the development of anoxic sediments and restriction of favorable conditions within the shallow redox layer.

3.4.4.a Infaunal Invertebrate Communities

Infaunal invertebrates constitute a diverse faunal assemblage within the South Slough estuary, and over 160 species have been recorded from the soft sediment littoral habitats (Table 3.12). Although the composition of infaunal communities has not been investigated in a systematic manner within the entire South Slough estuary, it is possible to combine information from several different studies to discern spatial patterns in composition and abundance (Jefferts, 1977; Rudy and Rudy, 1983; Posey, 1986; Posey and Rudy, 1986, 1987; Rumrill, 1991; Hewitt, 1993; Pregnall, 1993; Rumrill and Christy, 1996).

Table 3.12. Species list for infaunal and epibenthic invertebrates identified from the South Slough NERR, OR. Higher classification and taxonomic identifications are listed in accordance with Austin (1985) and Kozloff (1987). Status column indicates biotic origins if known (NIAS / Non-Indigenous Aquatic Species; CRYP / Cryptogenic; Cohen and Carlton, 1995; Carlton, 2000). Geographical Ranges are from Austin (1985). Reference column indicates observation of species occurrence (A. Jefferts, 1977; B. Rudy and Rudy, 1983; C. Posey, 1985; D. Posey & Rudy, 1986; E. Rumrill, 1991; F. Hewitt, 1993; G. Pregnall, 1993; H. Rumrill & Christy, 1996).

Classification	Genus & species	Biotic Status	Geographic Range	Reference
P. Aschelminthes:				
C. Nematoda				A,E
P. Nemertea:	*Nemertea* spp.			A,C,D,E,G
F. Amphiporidae	*Amphiporus imparispinosus*		BerS-Mex	B,E
F. Carinomidae	*Carinoma mutabilis*		BC-Mex	B
F. Cerebratulidae	*Cerebratulus californiensis*		Wa-Mex	B
F. Lineidae	*Lineus ruber*		NWPac-Ak, SCal	B
F. Emplectonematidae	*Paranemertes peregrina*		Jap-Ak-Mex	B,E
F. Tubulanidae	*Tubulanus pellucidus*		Wa, N-SCal, NAtl	E,G
	Tubulanus polymorphus		Ak-SCal, NAtl	B
	Tubulanus sexlineatus		Ak-SCal	E
P. Cnidaria:				
C. Anthozoa	*Diadumene lineata*	NIAS	Ak-SCal, circumpolar	B
	Metridium senile		Ak-SCal, circumpolar	D,E
	Nematostella vectensis	CRYP	Circumpolar, CCal	B,E
P. Platyhelminthes:				
C. Turbellaria				A
P. Phoronida:	*Phoronopsis harmeri*		BC-SCal, NWPac, CAm, Atl	A
	Phoronis pallida		C-SCal, Austr, NAtl	G
P. Annelida:				
C. Oligochaeta				A
	Tubificoides spp.		BC-SCal, NAtl	E
C. Polychaeta				
F. Arenicolidae	*Abarenicola pacifica*		Jap, Ak-NCal	B,C,E
F. Capitellidae	*Capitella* spp.	CRYP	SAk-SCal, cosmo	C,G,E
	Capitella capitata		C-SCal	A,B
	Heteromastus filiobranchus		BC-SCal	E
	Heteromastus filiformis	NIAS	SAk-SCal, NAtl, Arct	A,D
	Mediomastus acutus			A
	Mediomastus californiensis		BC-Mex	A,C,D,E
	Neomediomastus glabrus		Cal	A
	Notomastus magnus		Or, CCal-Mex	G
F. Cirratulidae	*Cirriformia spirabranchia*		Wa, C-SCal	D,E,G,H
F. Glyceridae	*Glycera robusta*		BC-SCal, Jap	B,E,G
	Glycera tenuis		Or-SCal, WAtl	A
	Hemipodus borealis		SAk-SCal	D
	Hemipodus californiensis		C-SCal	C,D
F. Goniadidae	*Glycinde armigera*		SAk-Baja, NWPac	A,B,C,D,E,G,H
	Glycinde polygnatha		Ak-SCal	C,E
F. Lumbrineridae	*Lumbrineris latreilli*		SAk-Peru, cosmo	A
	Lumbrineris zonata		SAk-Baja	B

Table 3.12 Continued next page

Table 3.12 Continued

Classification	Genus & species	Biotic Status	Geographic Range	Reference
F. Magelonidae	*Magelona pitelkai*		C-SCal	A
F. Maldanidae				H
F. Nephtyidae	*Nephtys caeca*		NWPac-CCal, circumboreal, NAtl	B,E,H
	Nephtys caecoides		BC-Mex	B,C,D,E
	Nephtys californiensis		BC-Mex	D
	Nephtys longosetosa		BC-Panama, circumpolar	E
F. Nereidae	*Nereis acuta*			D
	Nereis brandti		NWPac-SCal	B,D,E
	Nereis limnicola		BC-Cal	B,E
	Nereis procera		SAk-SCal	D
	Nereis succinea	NIAS	C-SCal, cosmo	D
	Nereis vexillosa		Ak-SCal	D,E
	Platynereis bicanaliculata		BC-SCal	G
F. Opheliidae	*Armandia brevis*		SAk-CCal	B,C,D,E,G
	Ophelina acuminata	NIAS	Ak-Mex, NAtl	E
F. Orbiniidae	*Haploscoloplos elongatus*		Ak-SCal	C
	Scoloplos armiger		NWPac-SCal, Arct, NAtl	D,E
	Leitscoloplos panamensis		Ak-Panama	A
	Naineris dendritica		Ak-SCal	D
F. Oweniidae	*Owenia fusiformis*		NWPac-Arct-Or, NAtl	C
F. Paraonidae	*Paraonella platybranchia*		BC-SCal	A,C,D,E
F. Phyllodocidae	*Eteone californica*		SAk-SCal	A,C,E
	Eteone dilatae		CCal-Mex	C
	Eteone lighti		C-SCal	B,E
	Eteone longa	NIAS	NWPac-SCal, Arct, NAtl	E
	Eteone pacifica		BC-SCal	B,E
	Eulalia bifoliata		C-SCal	D
	Phyllodoce castanea		NWPac-SCal, WPac, Ind	D
F. Polynoidae	*Halosydna brevisetosa*		Ak-SCal	B
	Hesperonoe complanata		BC-SCal	E,G
F. Sabellidae	*Chone eucaudata*		Ak-SCal, Jap	A
	Fabricia sabella	CRYP	BC-Or, SCal, Atl	A
	Manayunkia aestuarina		BC, Atl	E
F. Spionidae	*Boccardia proboscidea*		BC-SCal, NWPac, Panama	C,E
	Polydora cornuta	NIAS	BC-Mex, NAtl	A,C,D,E,H
	Polydora nuchalis		C-SCal	B,E
	Pseudopolydora kempi	NIAS	BC-SCal, SPac, Ind	C,E
	Pygospio elegans		BC-SCal NWPac, Atl	A,C,D,E
	Rhyncospio gluteaea		BC-Wa, Atl	A,C
	Spio filicornis		NWPac-CCal, Arct, cosmo	C,D
	Spiophanes bombyx		NWPac-SCal, SWPac, NAtl, cosmo	C,D
	Streblospio benedicti	NIAS	BC-SCal, NAtl	A,C,E
F. Syllidae	*Ehlersia cornuta*		Ak-Panama, cosmo	A
F. Terebellidae	*Eupolymnia crescentis*		Ak-Mex	E,G
	Neoamphitrite robusta		Ak-SCal	G
	Pista pacifica		BC-SCal	B,D,E,G
P. Mollusca:				
C. Bivalvia				
F. Cardiidae	*Clinocardium nuttallii*		NWPac-BerS-SCal	A,D,E,G
F. Mactridae	*Tresus capax*		SAk-CCal	B,E
F. Myidae	*Cryptomya californica*		Ak-CAmer	B,C,E,G,H
	Mya arenaria	NIAS	NWPac-CCal, Atl	A,B,D,E,H

Table 3.12 Continued next page

Table 3.12 Continued

Classification	Genus & species	Biotic Status	Geographic Range	Reference
F. Mytilidae	*Adula californiensis*		BC-SCal, Jap	E
	Mytilus sp.		Arct-Baja	C,D,E
	Mytilus trossulus		NPac	H
	Modiolus modiolus		NWPac, Arct-Baja, Atl	A
F. Ostreidae	*Crassostrea gigas*	NIAS	Jap, BC-Cal	E,G
	Ostrea conchaphila		SAk—Baja	E
F. Pholadidae	*Penitella penita*		SAk-Baja	E
	Zirfaea pilsbryi		Ak-Baja	E
F. Tellinidae	*Macoma balthica*		NWPac-Ak-NCal, Atl	B,C,D,E
	Macoma inquinata		Aleut-SCal	A,B,D,E,G,H
	Macoma nasuta		Ak-Baja	A,C,D,E,G,H
	Macoma secta		SAk-Baja	A
F. Teredinidae	*Bankia setacea*		NWPac	B,E
F. Veneridae	*Protothaca staminea*		Ak-Baja, Arct	B,C,E,G
	Saxidomus giganteus		Ak-CCal-Baja	C,G,E
	Transennella tantilla		SAk-Baja	A,B,E,G
	Transennella sp.		SAk-Baja	C,G
C. Gastropoda				C,D
F. Aglajidae	*Melanochlamys diomedia*		Ak-SCal	A
F. Archidorididae	*Archidoris montereyensis*		SAk-SCal	E
F. Assimineidae	*Assiminea californica*		BC-Baja	B,E
F. Melampidae	*Ovatella myosotis*	NIAS	BC-Baja, Atl	B,E
F. Naticidae	*Polinices lewisii*		SAk-Baja	E
F. Nucellidae	*Nucella lamellosa*		SAk-SCal	E
F. Olividae	*Olivella biplicata*		SAk-Baja	E
F. Stiligeridae	*Alderia modesta*		BC-SCal, Atl	B,E
F. Tergipedidae	*Tenellia adspersa*	NIAS	NAtl, CCal	A
P. Arthropoda:				
C. Ostracoda				A,C,H
C. Copepoda	*Eurytemora* sp.		NWPac-CCal	A
O. Harpacticoida				A
C. Crustacea				
O. Cumacea				C,H
	Cumella vulgaris		SAk-Wa, CCal	A,D,E
	Nippoleucon hinumensis	NIAS	Wa-Cal, Jap	A
	Hemileucon comes			D
O. Tanaidacea				
	Leptochelia dubia	CRYP	BC-SCal, Pac, Atl	A,B,C,D,E,G
	Pancolus californiensis		BC-SCal	A
	Sinelobus sp.	NIAS	BC-SCal, circumtropic	E
O. Isopoda				C,D
	Gnorimosphaeroma insulare		SAk-SCal	B,E
	Ianiropsis kincaidi		BerS-SCal	B
	Idotea wosnesenskii		NWPac-Baja	B,E
	Idotea resecata		SAk-Baja	B,E,G
	Ligia pallasii		Aleut-CCal	B,E
	Limnoria tripunctata	NIAS	BC-SCal, Atl	B
O. Amphipoda				
F. Ampithoidae	*Ampithoe dalli*		Aleut-Or	E
	Ampithoe lacertosa		Ak-Baja, NWPac	B,E
	Ampithoe valida	NIAS	BC-SCal, NWPac, WAtl	A,C,D,E
	Perampithoe lindbergi		NWPac-BerS-SCal	E

Table 3.12 Continued next page

Table 3.12 Continued

Classification	Genus & species	Biotic Status	Geographic Range	Reference
F. Anisogammaridae	*Eogammarus* sp.		Ak-SCal	D
	Eogammarus confervicolus		Ak-SCal	E,H
F. Aoridae	*Grandidierella japonica*	NIAS	Jap, N-CCal	C,E
F. Corophiidae	*Corophium* spp.		cosmo	C,D,H,E
	Corophium acherusicum	NIAS	Ak-Baja, Atl	A
	Corophium brevis		Ak-CCal	A,B,E
	Corophium salmonis		Ak-Or	B,E
	Corophium spinicorne		Ak-CCal	B,E
F. Gammaridae	*Gammarid* spp.		BerS-BC, Arct, NAtl	D,G
F. Haustoridae	*Eohaustorius* sp.		BC-SCal	C,E
F. Hyalidae	*Allorchestes angusta*		NWPac-SCal	A,B,E
F. Phoxocephalidae	*Eobrolgus spinosus*	NIAS	Wa-SCal, Atl	A,C,D,E
	Rhepoxynius epistomus		BC-Wa	A
F. Talitridae	*Traskorchestia traskiana*		Aleut-Baja	B,E
O. Decapoda				
F. Alpheidae	*Betaeus harrimani*		SAk SCal	E
F. Crangonidae	*Crangon alaskensis*		Ak-SCal	B,E
	Crangon franciscorum		Ak-SCal	A,B,E
	Crangon nigricauda		Ak-Baja	E
	Lissocrangon stylirostris		Ak-SCal	B,E
F. Hippolytidae	*Eualus biunguis*		NWPac-Or	E
	Heptacarpus paludicola		C-SCal	B,E,G
	Heptacarpus pictus		C-SCal	B,E
	Hippolyte clarki		SAk-Wa, SCal	E
F. Upogebiidae	*Upogebia pugettensis*		SAk-Baja	B,C,D,E,G
F. Callianassidae	*Neotrypaea californiensis*		Ak-SCal, NWPac	B,C,D,E
F. Cancridae	*Cancer magister*		Aleut-Baja	B,E,G
	Cancer oregonensis		Ak-SCal	E
	Cancer productus		Ak-SCal	B,E
F. Grapsidae	*Hemigrapsus nudus*		Ak-Baja	E
	Hemigrapsus oregonensis		Ak-Baja	C,D,E,G
	Pachygrapsus crassipes		Or-Baja, NWPac	E,G
F. Majidae	*Pugettia gracilis*		Ak-Baja	E
	Pugettia producta		Ak-Baja	B,E,G
F. Paguridae	*Pagurus hirsutiusculus*		NWPac-SCal	B,E
F. Pinnotheridae	*Pinnixa* spp.		Ak-Baja	E,G
	Scleroplax granulata		BC-Baja	E,G
F. Porcellanidae	*Petrolisthes cinctipes*		BC-Baja	E
F. Portunidae	*Carcinus maenas*		Atl, WPac, Wa	E
F. Xanthidae	*Lophopanopeus bellus*		Ak-SCal	E
	Rithropanopeus harrisii	NIAS	NAtl, Or, CCal	B,E
P. Echinodermata:				
C. Asteroidea	*Pisaster brevispinus*		Ak-SCal	E
C. Ophiuroidea	*Amphiodia* sp.		NWPac-Mex	E, G

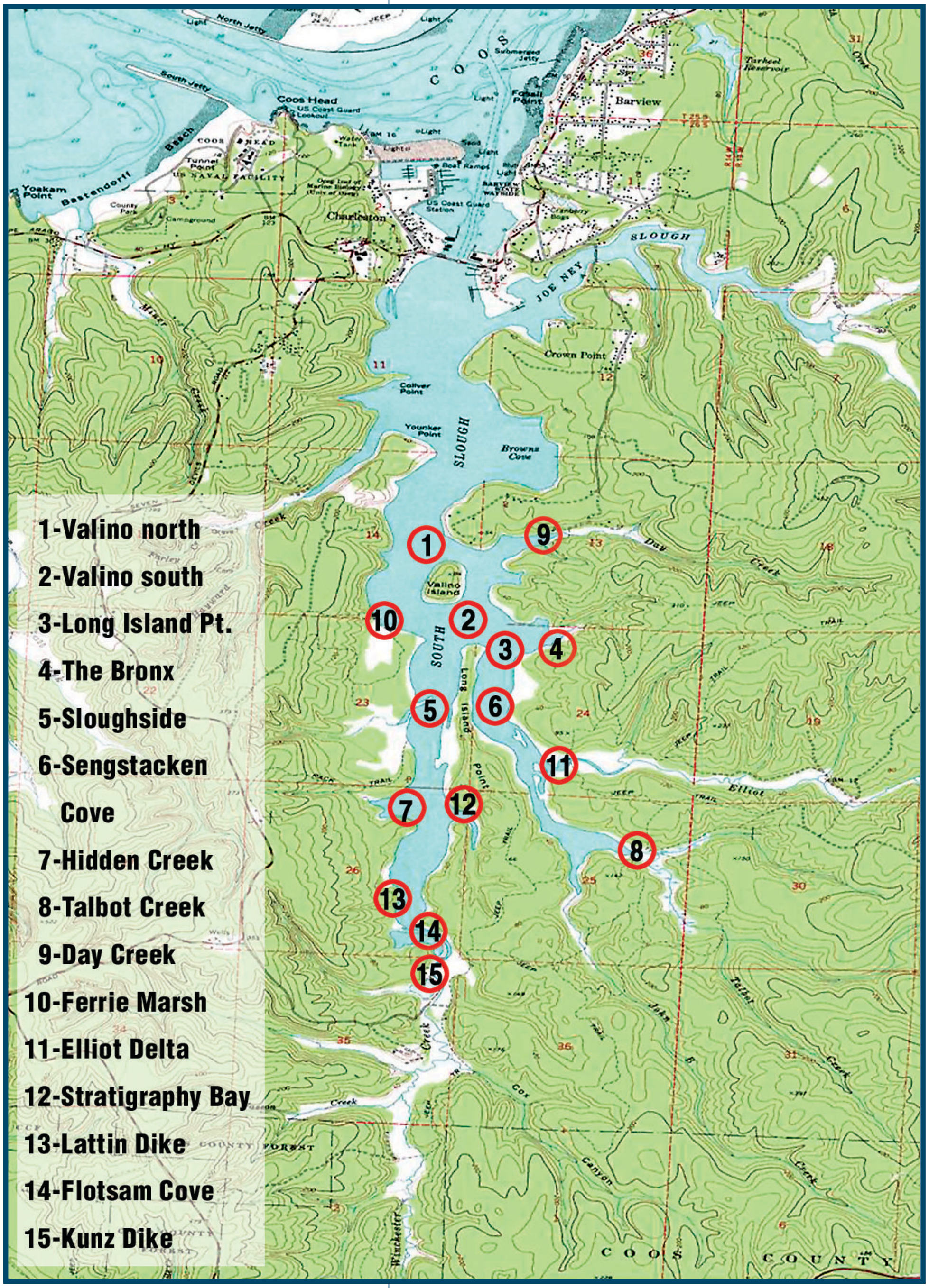


Figure 3.31. Location of study sites within the South Slough NERR during a survey of infaunal invertebrate communities (Rumrill, 1991; see Tables 3.13 and 3.14).

Jefferts (1977) collected depth-stratified core samples from several locations along the South Slough estuarine gradient (from Charleston to Hidden Creek) for the purpose of comparison with samples from the Coos Bay shipping channel. Descriptive records of species composition and abundance were assembled to allow computation of metrics for infaunal community richness, diversity, and evenness. Rudy and Rudy (1983) produced an illustrated and annotated guide to the identification and natural history of selected species primarily as an educational tool. In contrast, Posey (1986), Posey and Rudy (1987), Pregnall (1993), and Rumrill and Christy (1996) conducted experimental investigations of ecological interactions among distinct elements of the soft sediment community in the marine-dominated region near Valino Island. Their reports include records of species occurrence and density within a series of manipulated and control plots. Finally, Rumrill (1991) conducted an intensive sampling program that was stratified within intertidal tideflat habitats throughout the South Slough National Estuarine Research Reserve (NERR; see Figure 3.31). Field sampling protocol during the census included a combination of standard sediment cores and larger-volume box cores excavated from the low, mid, and high intertidal zone. Although these investigations span nearly two decades, their seasonal and spatial overlap is considerable; most field samples were collected from the low to mid intertidal zone during spring or summer months. Direct comparisons among these datasets should be made with caution, however, because the investigators designed their studies to meet different objectives, and because they used different core sizes and techniques to collect and process their samples.

The infaunal and epibenthic invertebrate community within the South Slough estuary is comprised primarily of polychates (62 genera, 38% of all reported genera), decapod crustaceans (26 genera, 16%), bivalve molluscs (21 genera, 13%), and amphipods (17 genera, 10%). These four groups total 77% of the recorded genera and species (Figure 3.32), with the remainder contributed by gastropod molluscs (9 genera, 5%), nemerteans (8 genera, 5%), isopods (6 genera, 4%) and other smaller groups (cnidarians, platyhelminthes, phoronids, cumaceans, tanaids, echinoderms; combined total < 10%). The list of larger macroinvertebrates was compiled from descriptions of infaunal and epibenthic organisms retained on 0.5 mm and 1 mm mesh screens; it does not include numerous species of smaller infauna, primarily nematodes, oligochaetes, and epibenthic harpacticoid copepods.

Rumrill (1991) conducted a survey of intertidal invertebrate communities within mudflats, sandflats, eelgrass beds, and salt marsh habitats throughout the marine-dominated, mesohaline, and riverine regions of the South Slough NERR (Figures 3.31, 3.32; Tables 3.13, 3.14). The four major groups of infaunal and epifaunal invertebrates exhibit a strong spatial pattern across the South Slough estuarine gradient (Figure 3.32). The invertebrate community is consistently most diverse in the marine-dominated region of the estuary where the intertidal habitats are a

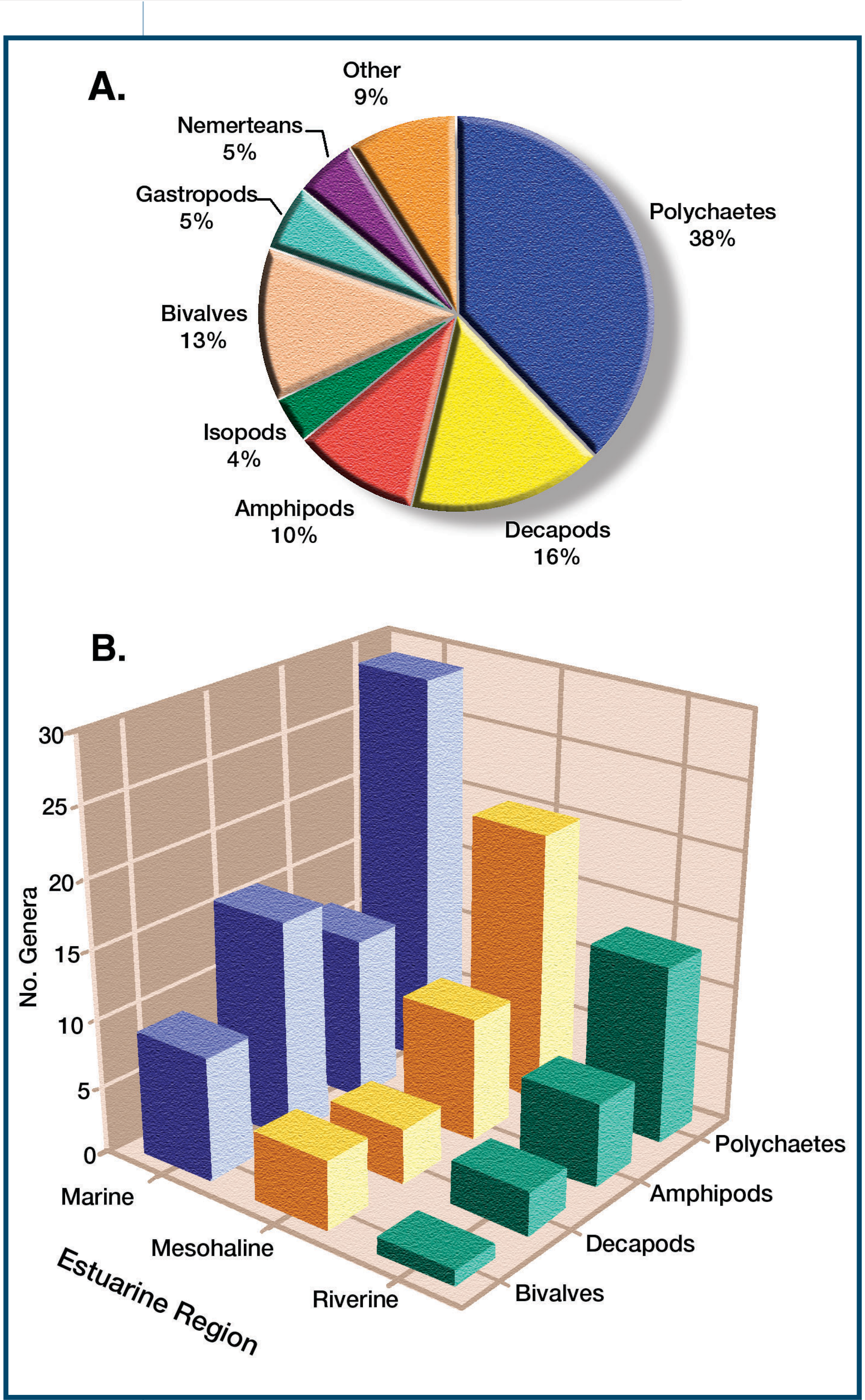


Figure 3.32. Soft-sediment invertebrate communities within the South Slough estuary, OR. A. Higher-level composition of soft-sediment invertebrate fauna (from Table 3.12). B. Spatial pattern of infaunal invertebrate genera along the estuarine gradient within the South Slough NERR (from Rumrill, 1991; Tables 3.13 and 3.14).

Table 3.13. Composition, distribution, and abundance of infaunal invertebrates from soft-sediment habitats within the marine-dominated region of the South Slough NERR. Values indicate mean no. individuals per m^2 from upper 10 cm of sediment in the low intertidal zone; samples from 5 replicate 0.25 m^2 quadrats and 5 replicate 0.0034 m^2 cores are pooled. Benthic samples collected and identified by Rumrill (1991). Marine-dominated region = Sites 1, 2, 3, 4, 9, 10 (see Figure 3.31 for location of sample sites).

South Slough NERR Location:	Site 1 Valino Is. (N)	Site 2 Valino Is. (S)	Site 3 Long Is. Pt.	Site 4 Bronx Cove	Site 9 Day Creek	Site 10 Ferrie Head
Distance from mouth:	4.1 km	4.7 km	5.2 km	5.5 km	4.5 km	4.7 km
Sediment type:	sand mud	sand mud	sand mud	sand	mud	sand mud
Habitat type:	*Zostera*	unvegetated	*Zostera* oysters	burrow shrimp	burrow shrimp *Zostera*	*Zostera*
Taxon						
P. Aschelminthes:						
C. Nematoda						
P. Nemertea:						
Nemertea spp.		1			1	2
Amphiporus imparispinosus		1	1			
Paranemertes peregrina	1		3			3
Tubulanus pellucidus			1			
Tubulanus sexlineatus	1	1	3			3
P. Cnidaria:						
Metridium senile			1			
Nematostella vectensis						
P. Annelida:						
C. Oligochaeta:						
Tubificoides spp.						
C. Polychaeta:						
Abarenicola pacifica	16	12	26		16	12
Capitella spp.	418	310	2275	413	103	117
Heteromastus filiobranchus	207		517	207		221
Mediomasus californiensis	103	207	1138		103	1442
Cirriformia spirabranchia					1	11
Glycera robusta			4			5
Glycinde armigera	1	1	12	1	13	31
Glycinde polygnatha						
Nephtys caeca		3			1	13
Nephtys caecoides	3	20	10	1	24	31
Nephtys longosetosa					2	3
Nereis brandti	1	1	2			
Nereis limnicola						
Nereis vexillosa	21	29	5		64	
Armandia brevis		414	207			517
Ophelina acuminata					2068	207
Leitoscoloplos armiger	207	310				
Paraonella platybranchia	207					620
Eteone californica	517	724	310		414	620
Eteone lighti					207	
Eteone longa						
Eteone pacifica	103	103	310			620

Table 3.13 Continued next page

Table 3.13 Continued

South Slough NERR Location:	Site 1 Valino Is. (N)	Site 2 Valino Is. (S)	Site 3 Long Is. Pt.	Site 4 Bronx Cove	Site 9 Day Creek	Site 10 Ferrie Head
Distance from mouth:	**4.1 km**	**4.7 km**	**5.2 km**	**5.5 km**	**4.5 km**	**4.7 km**
Sediment type:	**sand** **mud**	**sand** **mud**	**sand** **mud**	**sand**	**mud**	**sand** **mud**
Habitat type:	***Zostera***	**unvegetated**	***Zostera*** **oysters**	**burrow shrimp**	**burrow shrimp** ***Zostera***	***Zostera***
F. Polynoidae spp.	124	207				
Hesperonoe complanata	15	15	7	18	5	16
Manayunkia aestuarina						
Boccardia proboscidea	207	517	1861	207	103	3826
Polydora cornuta	41	41	124		17	126
Polydora nuchalis						
Pseudopolydora kempi	310	310			517	1758
Pygospio elegans	6824	4653	956	310	724	3516
Streblospio benedicti	207		1862		103	827
Eupolymnia crescentis	53869	8583	4550	413	31129	12056
Pista pacifica	2	1			1	3
P. Mollusca:						
C. Bivalvia						
Clinocardium nuttallii	3	3			1	8
Tresus capax						
Cryptomya californica	16	1	7	28	1	35
Mya arenaria	3		19	1	3	4
Adula californiensis						
Mytilus sp.						
Crassostrea gigas						
Ostrea conchaphila						
Penitella penita						
Zirfaea pilsbryi						
Macoma balthica	26		4		3	62
Macoma inquinata	16	6	8		24	79
Macoma nasuta	20		6			93
Bankia setacea						
Protothaca staminea	1					7
Saxidomus giganteus	1					2
Transennella tantilla						6
C. Gastropoda						
Archidoris montereyensis	1					
Assiminea californica						
Ovatella myosotis						
Polinices lewisii						
Nucella lamellosa	1		4			
Olivella biplicata						
Alderia modesta						
P. Arthropoda						
C. Crustacea						
O. Cumacea:						
Cumella vulgaris	207		103			1241
Leptochelia dubia	28544	38989	3723		13134	37645
Sinelobus sp.					1448	
O. Isopoda:						
Gnorimosphaeroma insulare						
Idotea wosnesenskii						
Idotea resecata						5
Ligia pallasii						

Table 3.13 Continued next page

Table 3.13 Continued

South Slough NERR Location:	Site 1 Valino Is. (N)	Site 2 Valino Is. (S)	Site 3 Long Is. Pt.	Site 4 Bronx Cove	Site 9 Day Creek	Site 10 Ferrie Head
Distance from mouth:	4.1 km	4.7 km	5.2 km	5.5 km	4.5 km	4.7 km
Sediment type:	sand mud	sand mud	sand mud	sand	mud	sand mud
Habitat type:	*Zostera*	unvegetated	*Zostera* oysters	burrow shrimp	burrow shrimp *Zostera*	*Zostera*
O. Amphipoda:						
Ampithoe dalli		103	620			1758
Ampithoe lacertosa	103		103			310
Ampithoe valida	207	414		207	414	
Perampithoe lindbergi		103				
Eogammarus confervicolus	310	103				620
Grandidierella japonica						
Corophium spp.	620	517	3103		1758	3827
Corophium brevis	207					
Corophium salmonis	207				103	
Corophium spinicorne						
Eohaustorius sp.	310	103				
Allorchestes angusta	103					
Eobrolgus spinosus	517	414			1965	
Traskorchestia traskiana						1
O. Decapoda						
Betaeus harrimani						
Crangon alaskensis	1		4			1
Crangon franciscorum	1	1	1		2	
Crangon nigricauda						
Lissocrangon stylirostris	1		1			
Eualis biunguis		11				
Heptacarpus paludicola	1	2	6			2
Heptacarpus pictus	1		6		1	1
Hippolyte clarki					2	
Upogebia pugettensis	2		12		6	8
Neotrypaea californiensis				18		
Cancer magister (1st molt)	87	564	6		74	5
Cancer oregonensis		4				1
Cancer productus						
Hemigrapsus nudus						1
Hemigrapsus oregonensis		6	4			5
Pachygrapsus crassipes						
Pugettia gracilis						
Pugettia producta						
Pagurus hirsutiusculus	1					
Pinnixa spp.						1
Scleroplax granulata						
Petrolisthes cinctipes						
Carcinus maenas						
Lophopanopeus bellus						
Rithropanopeus harrisii	1		2			2
P. Echinodermata:						
C. Asteroidea						
Pisaster brevispinus						
C. Ophiuroidea						
Amphiodia sp.	1					

mixture of sandy mud, mud, shell rubble, burrowing shrimp beds, and eelgrass beds (Table 3.13). Invertebrate communities exhibit intermediate diversity within the middle (mesohaline) region where the littoral habitats include mud, shell rubble, and eelgrass beds. Lowest invertebrate diversity was observed within the upper riverine region within predominantly mud and eelgrass habitats (Table 3.14). Polychaetes and amphipods exhibited a gradual decline in diversity along the estuarine gradient, while decapods and bivalves exhibited sharp decreases with increasing exposure to freshwater influence. Although the frequency of sampling has been substantially lower in the mesohaline and riverine regions in comparison to the marine-dominated region, the spatial pattern of decreasing invertebrate diversity along the estuarine gradient is robust and constitutes a fundamental biotic characteristic of the South Slough estuary.

Composition of the infaunal invertebrate community is numerically dominated within the marine-dominated region of the South Slough by tanaids (*Leptochelia dubia*; 37,000 individuals m^{-2}), several species of polychaetes (*Pygospio elegans, Boccardia proboscidea, Capitella* spp., *Streblospio benedicti, Pseudopolydora kempi, Eteone californica*; 10,750 to 2,850 indv. m^{-2}), amphipods (*Corophium* spp., *Ampithoe valida, Eobrolgus spinosus*; 2,500 to 830 indv. m^{-2}) and cumaceans (*Cumella vulgaris*; 670 indv. m^{-2}; Posey (1986); Posey and Rudy (1987)). Domination of the infaunal invertebrate community by tanaids and polychates in the mid 1980's is consistent with observations conducted in a variety of habitats in the early 1990's. Densities of *Leptochelia dubi*a (39,000 to 4,000 indv. m^{-2}) and the polychaetes (*Pygospio elegans, Boccardia proboscidea, Pseudoploydora kempi, Streblospio benedicti*; 7,000 to 2,000 indv. m^{-2}) were the highest observed in the intertidal soft-sediment habitats (Table 3.13). Rumrill (1991) also observed high densities of the terrebellid polychaete *Eupolymnia cresentis* (54,000 to 4,000 indv. m^{-2}), and the capitellid polychaete *Mediomastus californiensis* (1,400 indv. m^{-2}), and substantially lower densities of *Capitella* spp. (2,200 to 120 indv. m^{-2}). These observations of infaunal invertebrate communities are also consistent with descriptions by Everett *et al.,* (1995) and Pregnall (1993). Composition of the infaunal invertebrate communities and assemblages of bivalve molluscs within the marine dominated region of the South Slough appear to be representative of other drowned river-mouth estuaries in the Pacific northwest region (Simenstad, 1983; Yaquina Bay / Castillo, 2000; Tillamook Bay / Golden *et al.,* 1998; Hinzman and Nelson, 1998; Willapa Bay / Ferraro and Cole, 2001).

By comparison with the marine region, intertidal soft-sediment habitats located in the mesohaline and riverine regions of the South Slough are inhabited by fewer species of infaunal and large epifaunal invertebrates (Figure 3.32, Table 3.14). The mesohaline infaunal assemblage is numerically dominated by amphipods (*Corophium* spp.; up to 3,300 individuals m^{-2}), small polychaetes (*Etone lighti, E. longa, Polydora cornuta, Pygospio elegans*; 2,500 to 1,800 m^{-2}), and tanaids (*Leptochelia dubia*; up to 1,500 m^{-2}). In contrast, soft-sediment habitats in the riverine region are numerically dominated by amphipods (*Corophium* spp.; 2,300 to 1,200 m^{-2}), sponid and terrebellid polychaetes (*Pygospio elegans, Eupolymnia cresentis*; 1,500 to 1,00 m^{-2}), and tanaids (*L. dubia*; up to 1,100 m^{-2}). Jefferts (1977) reported that the infaunal invertebrate assemblage at Hidden Creek (mesohaline region) was dominated by the sedentary capitellid polychaete *Mediomastus acutus* (2,250 m^{-2}) while the samples collected in 1991 were dominated by predatory phyllodocid worms (*Eteone* spp.) and sedentary spionid polychaetes (detritus feeders; Table 3.14). This apparent difference in the polychaete assemblage may be an artifact of sampling within the heterogeneous intertidal habitat, but it may also reflect a significant ecological change in the benthic infaunal community. Other than these differences in genera and species, the overall composition of the infaunal invertebrate assemblages within the mesohaline and riverine regions of the South Slough are similar to those reported by Jefferts (1977) and Frank *et al.,* (1990).

A variety of bivalve molluscs are harvested regularly from the South Slough estuary during low tides by recreational diggers. The most popular clam beds are located near the mouth of the estuary at the Portside tideflats, and immediately south of the Charleston Bridge at the Metcalf tideflats. Other popular recreational clam sites include the Indian Point tideflats, Browns Cove, and the intertidal sand and mudflats on the north side of Valino Island. Large numbers of gaper clams (*Tresus capax*), butter clams (*Saxidomus giganteus*), cockles (*Clinocardium nuttalli*), littleneck clams (*Protothaca staminea*), and softshell clams (*Mya arenaria*) are taken regularly from the South Slough estuary, and smaller numbers are harvested from sites located within the administrative boundaries of the South Slough National Estuarine Research Reserve. In combination, tideflats located within the South Slough estuary provided about 25% of the marine organisms harvested by recreational diggers in the entire Coos estuary (Gaumer *et al.,* 1973). Intertidal tideflats located near the Charles-

Table 3.14. Composition, distribution, and abundance of infaunal invertebrates from soft-sediment habitats within the mesohaline (middle) and riverine regions of the South Slough NERR. Values indicate mean no. individuals per m^2 from upper 10 cm of sediment in the low intertidal zone; samples from 5 replicate 0.25 m^2 quadrats and 5 replicate 0.0034 m^2 cores are pooled. Benthic samples collected and identified by Rumrill (1991). Mesohaline region = Sites 6, 7, 12; Riverine region = Sites 8, 14, 15 (see Figure 3.31 for location of study sites).

South Slough NERR Location:	Site 6 Seng Cove	Site 7 Hidden Cove	Site 12 Strat Bay	Site 8 Talbot Creek	Site 14 Flotsom Cove	Site 15 Winch Creek
Estuary Region:	**Meso-haline**	**Meso-haline**	**Meso-haline**	**Riverine**	**Riverine**	**Riverine**
Distance from mouth:	**6.0 km**	**6.6 km**	**6.7 km**	**7.6 km**	**7.6 km**	**7.9 km**
Sediment type:	**smud**	**mud**	**mud**	**mud**	**mud**	**mud**
Habitat type:	***Zostera* patchy**	***Zostera* patchy**	**unvegetated**	***Zostera* patchy**	***Zostera* patchy**	***Zostera***
Taxon						
P. Aschelminthes:						
C. Nematoda						
P. Nemertea:						
Nemertea spp.			1		1	
Amphiporus imparispinosus						
Paranemertes peregrina	1				1	
Tubulanus pellucidus						
Tubulanus sexlineatus						
P. Cnidaria						
Metridium senile						
Nematostella vectensis						
P. Annelida						
C. Oligochaeta						
Tubificoides spp.						
C. Polychaeta						
Abarenicola pacifica	22	11	16	21		
Capitella spp.	1655	620	414	620	414	103
Heteromastus filiobranchus		103				
Mediomasus californiensis	310	310				
Cirriformia spirabranchia						
Glycera robusta		2				
Glycinde armigera	6	3		3		
Glycinde polygnatha	3					
Nephtys caeca						
Nephtys caecoides				2	17	
Nephtys longosetosa						
Nereis brandti						
Nereis limnicola					27	
Nereis vexillosa	1	3				
Armandia brevis	1					
Ophelina acuminata	9		164	206	376	
Leitoscoloplos armiger						
Paraonella platybranchia						
Eteone californica	103	207	103			
Eteone lighti	827	103	2482	206	310	103
Eteone longa		414	1339			
Eteone pacifica						
F. Polynoidae spp.						
Hesperonoe complanata		310			103	

Table 3.14 Continued next page

Table 3.14 Continued

South Slough NERR Location:	Site 6 Seng Cove	Site 7 Hidden Cove	Site 12 Strat Bay	Site 8 Talbot Creek	Site 14 Flotsom Cove	Site 15 Winch Creek
Estuary Region:	**Meso-haline**	**Meso-haline**	**Meso-haline**	**Riverine**	**Riverine**	**Riverine**
Distance from mouth:	**6.0 km**	**6.6 km**	**6.7 km**	**7.6 km**	**7.6 km**	**7.9 km**
Sediment type:	**smud**	**mud**	**mud**	**mud**	**mud**	**mud**
Habitat type:	***Zostera* patchy**	***Zostera* patchy**	**unvegetated**	***Zostera* patchy**	***Zostera* patchy**	***Zostera***
Manayunkia aestuarina				724	414	1648
Boccardia proboscidea	414					
Polydora cornuta	103	414	1442			
Polydora nuchalis				1551	206	103
Pseudopolydora kempi	724	103	207			
Pygospio elegans	827	724	1758		1551	
Streblospio benedicti	414	414	103	103	103	
Eupolymnia crescentis	1345	517	931	1034	1034	
Pista pacifica						
P. Mollusca:						
C. Bivalvia						
Clinocardium nuttallii						
Tresus capax						
Cryptomya californica		1				
Mya arenaria	37	9		2	5	
Adula californiensis						
Mytilus sp.						
Crassostrea gigas						
Ostrea conchaphila						
Penitella penita						
Zirfaea pilsbryi						
Macoma balthica	8	19	2			
Macoma inquinata	22	13	7			
Macoma nasuta		4	1			
Bankia setacea						
Protothaca staminea						
Saxidomus giganteus						
Transennella tantilla						
C. Gastropoda						
Archidoris montereyensis						
Assiminea californica						
Ovatella myosotis						
Polinices lewisii						
Nucella lamellosa						
Olivella biplicata						
Alderia modesta				2		
P. Arthropoda:						
C. Crustacea						
O. Cumacea						
Cumella vulgaris						
Leptochelia dubia	931	1138	1551	414	1133	310
Sinelobus sp.						
O. Isopoda						
Gnorimosphaeroma insulare						4
Idotea wosnesenskii						
Idotea resecata						
Ligia pallasii						2
O. Amphipoda						
Ampithoe dalli						

Table 3.14 Continued next page

Table 3.14 Continued

South Slough NERR Location:	Site 6 Seng Cove	Site 7 Hidden Cove	Site 12 Strat Bay	Site 8 Talbot Creek	Site 14 Flotsom Cove	Site 15 Winch Creek
Estuary Region:	**Meso-haline**	**Meso-haline**	**Meso-haline**	**Riverine**	**Riverine**	**Riverine**
Distance from mouth:	**6.0 km**	**6.6 km**	**6.7 km**	**7.6 km**	**7.6 km**	**7.9 km**
Sediment type:	**smud**	**mud**	**mud**	**mud**	**mud**	**mud**
Habitat type:	***Zostera* patchy**	***Zostera* patchy**	**unvegetated**	***Zostera* patchy**	***Zostera* patchy**	***Zostera***
Ampithoe lacertosa			310			
Ampithoe valida	47	310	515	103		17
Perampithoe lindbergi						
Eogammarus confervicolus	420		412	724		
Grandidierella japonica			210	210		
Corophium spp.	207	1448	3296	1241	2275	2172
Corophium brevis			103			
Corophium salmonis	310		827	414	210	
Corophium spinicorne						
Eohaustorius sp.			9			14
Allorchestes angusta						
Eobrolgus spinosus	1758	414	206			
Traskorchestia traskiana						
O. Decapoda						
Betaeus harrimani						
Crangon alaskensis					1	7
Crangon franciscorum	1					
Crangon nigricauda						
Lissocrangon stylirostris						
Eualis biunguis						
Heptacarpus paludicola						
Heptacarpus pictus						
Hippolyte clarki						
Upogebia pugettensis		2				
Neotrypaea californiensis		4				
Cancer magister (1st molt)	3	5	9	4	28	
Cancer oregonensis						
Cancer productus						
Hemigrapsus nudus						
Hemigrapsus oregonensis						
Pachygrapsus crassipes						
Pugettia gracilis						
Pugettia producta						
Pagurus hirsutiusculus						
Pinnixa spp.						
Scleroplax granulata					1	
Petrolisthes cinctipes						
Carcinus maenas						
Lophopanopeus bellus						
Rithropanopeus harrisii						
P. Echinodermata:						
Class Asteroidea						
Pisaster brevispinus						
Class Ophiuroidea						
Amphiodia sp.						

ton Bridge (Metcalf flats) had the highest densities of recreational clams during a survey conducted in 1971, but the highest catch per effort (CPU) values occurred at the Portside flat (Gaumer *et al.,* 1973). Population estimates for large bivalve molluscs within the Portside tideflats included *T. capax* (1,333,000 clams), *C. nuttalli* (348,000 clams), *P. staminea* (289,000 clams), *S. giganteus* (119,000 clams), and *M. arenaria* (50,000 clams; Gaumer, 1978). The Portside tideflats were estimated to support a total population of over 10 million recreational clams in 1978 (Gaumer, 1978).

Figure 3.33. Scanning electron micrograph of an unidentified harpacticoid copepod collected from an interstitial estuarine habitat, northern California. SEM by M. Hooge, 1999.

3.4.5 Epibenthic Invertebrates

Epibenthic invertebrates include those members of the meiofauna and small macrofauna that inhabit the sediment-water interface within estuarine tidal channels and mudflat habitats. Although they are recognized to serve an important ecological role as principal prey items for fishes and other secondary consumers (Alheit and Scheibel, 1982; Hicks and Coull, 1983; Simenstad, 1983), the composition, abundance, and distribution of epibenthic invertebrate communities have not been studied as a coherent functional group within the South Slough estuary. Distinct elements of the epibenthic invertebrate community (*i.e.,* microcrustaceans including gammarid amphipods, tanaids, and cumaceans) have been surveyed by several investigators (see Table 3.12), but information about other elements (primarily harpacticoid copepods, leptostracans, and ostracods) is lacking. Diverse assemblages of harpacticoid copepods are abundant in soft-sediment estuarine habitats in northern California (Hooge, 1999; Figure 3.33), and several genera of harpacticods (*i.e., Longipedia* sp., *Harpacticus* sp., *Tisbe* spp. *Robertsonia* sp., *Heterolaophonte* spp., and others) are seasonally abundant within eelgrass beds (both *Zostera marina* and *Z. japonica*), mudflats, and salt marshes in Padilla Bay, WA (Simenstad *et al.,* 1988), and they are undoubtedly an important component of invertebrate faunal assemblages in other Pacific northwest estuaries (Simenstad, 1983) including the South Slough.

3.5 Ecological Interactions within Estuarine Communities

The South Slough estuary has served as the study site for numerous investigations of ecological interactions among elements of the estuarine community. These investigations include empirical and field studies of fundamental ecological processes and environmental physiology, as well as applied studies that address national, regional, and local estuarine resource management issues.

3.5.1 Interspecific Interactions among Pacific Ghost Shrimp, Infaunal Invertebrates, and Predatory Sculpins

Pacific ghost shrimp (*Neotrypaea californiensis*) are highly mobile, burrowing deposit feeders that inhabit dense beds in soft sandy habitats within the marine-dominated region of the South Slough estuary. Continual burrowing activities associated with feeding by ghost shrimp results in extensive bioturbation of the surface sediments in the high and mid intertidal zone. Posey (1986) investigated the composition and abundance of macrofaunal invertebrate communities associated with dense beds of *N. californiensis* within the South Slough in order to test predictions regarding invertebrate community responses to sediment instability and disturbance. In

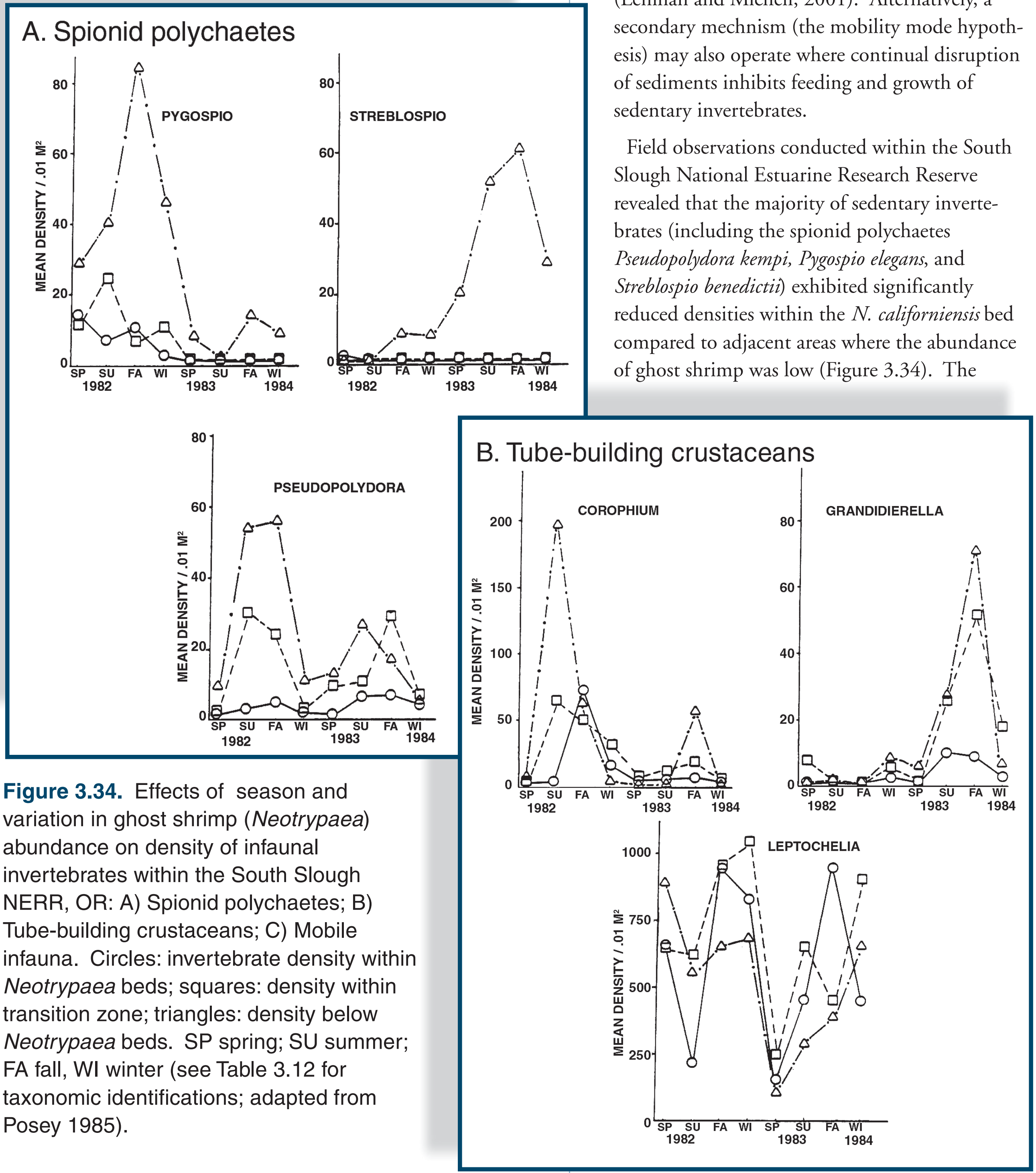


Figure 3.34. Effects of season and variation in ghost shrimp (*Neotrypaea*) abundance on density of infaunal invertebrates within the South Slough NERR, OR: A) Spionid polychaetes; B) Tube-building crustaceans; C) Mobile infauna. Circles: invertebrate density within *Neotrypaea* beds; squares: density within transition zone; triangles: density below *Neotrypaea* beds. SP spring; SU summer; FA fall, WI winter (see Table 3.12 for taxonomic identifications; adapted from Posey 1985).

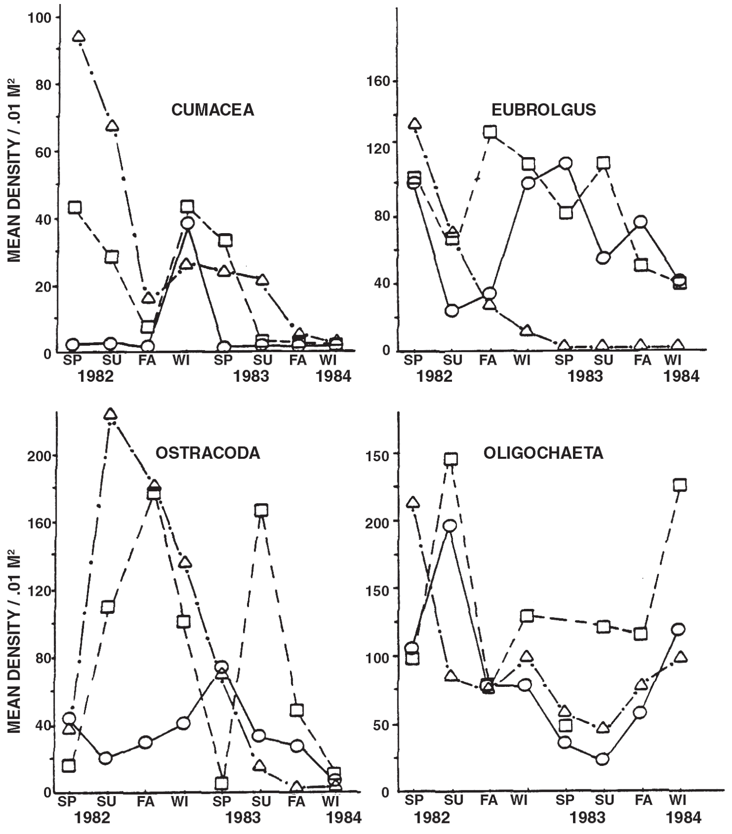
particular, Posey (1986) conducted field studies of interspecific relationships between burrowing shrimp and several species of infaunal invertebrates to determine the liklihood that trophic group amensalism was the primary interaction mechanism. Trophic group amensalism occurs in soft sediment communities when active bioturbation by deposit feeders has a direct negative effect on the persistence of suspension feeders by continual disruption of sediments to the extent that feeding is impaired (Lenihan and Micheli, 2001). Alternatively, a secondary mechnism (the mobility mode hypothesis) may also operate where continual disruption of sediments inhibits feeding and growth of sedentary invertebrates.

Field observations conducted within the South Slough National Estuarine Research Reserve revealed that the majority of sedentary invertebrates (including the spionid polychaetes *Pseudopolydora kempi, Pygospio elegans*, and *Streblospio benedictii*) exhibited significantly reduced densities within the *N. californiensis* bed compared to adjacent areas where the abundance of ghost shrimp was low (Figure 3.34). The abundance of two tube-building amphipods (*Corophium* spp. and *Grandidierella japonica*) was also negativly correlated with increased *N. californiensis* density. In contrast, the abundance of a tube-dwelling tanaid crustacean (*Leptochelia dubia*) and mobile oligochaetes (*Limnodriloides victoriensis* and others) varied independently of ghost shrimp density (Figure 3.34), while two mobile species (cumaceans and the amphipod *Eobrolgus spinosus*) also declined in response to the increased presence of ghost shrimp. Posey (1986) did not observe any changes in the overall taxonomic richness of infaunal invertebrate communities between the ghost shrimp areas (39 taxa) and shrimp-free sites (39 taxa). Differences in the responses of these infaunal invertebrates to natural variation in burrowing shrimp densities suggests that the mobility mode interaction serves to regulate community structure within the bioturbated sediments, and that trophic group amensalism is probably not the primary interaction mechanism within the intertidal mud and sandflat habitats.

The seaward limit of *Neotrypaea californiensis* beds is typically abrupt and characterized by an order of magnitude decline in ghost shrimp density over a horizontal distance of 1 to 2 m and a vertical profile of a few cm. Posey (1985) placed exclusion cages in the tideflats near Valino Island to investigate restriction of ghost shrimp densities by predatory fish. Results from these field experiments demonstrate that the lower distributional limit of *N. californiensis* is controlled by the foraging behavior of staghorn sculpins (*Leptocottus armatus*). Because the majority of infaunal invertebrates respond directly to bioturbation by ghost shrimp, predation by *L. armatus* upon adult ghost shrimp can potentially have indirect effects on the community structure of infaunal invertebrates, particularly at the transitional boundary between the low and mid intertidal zone.

C. Mobile infauna

Figure 3.34 Continued



3.5.2 Alteration of Eelgrass Community Structure by Mariculture of Pacific Oysters

Mariculture of Pacific oysters (*Crassostrea gigas*) is the principal anthropogenic activity that has ongoing environmental effects within the low intertidal tideflats and tidal channels of the South Slough estuary. Ecological impacts of commercial oyster culture on eelgrass beds (*Zostera marina*) were examined in a series of experimental treatment plots and unmanipulated control areas established within the marine-dominated region of the South Slough, near Ferrie Head (Everett *et al.,* 1995). Oysters were grown over a period of 2 years on a series of vertical wire stakes placed within an established eelgrass bed, and also suspended from wooden racks constructed within the eelgrass bed. Both stake and rack mariculture techniques resulted in significant decreases in the abundance of *Z. marina* compared to undisturbed control areas (Figure 3.35). Spatial cover of eelgrass declined within the experimental oyster mariculture stake plots to less than 25% of the cover values in the reference plots after 12 months (Figure 3.36), and eelgrass was absent from the rack treatments after 15 months (Figure 3.37). Monitoring of individually marked *Z. marina* plants demonstrated that there were no differences in the growth rates of eelgrass between the oyster mariculture and control plots.

Comparisons of sediment surface topography demonstrated that oyster culture resulted in significantly greater sediment deposition in stake plots and greater erosion in the rack plots (Figure 3.38). It is likely that physical disturbance caused by placement of the oyster stakes and high sedimentation rates within the stake array combined to produce a negative effect on *Z. marina* density. In contrast, sediment erosion and shading most likely resulted in the rapid decline in eelgrass within the rack culture areas. Results from these field experiments suggest that losses of *Z. marina* habitat may be substantial

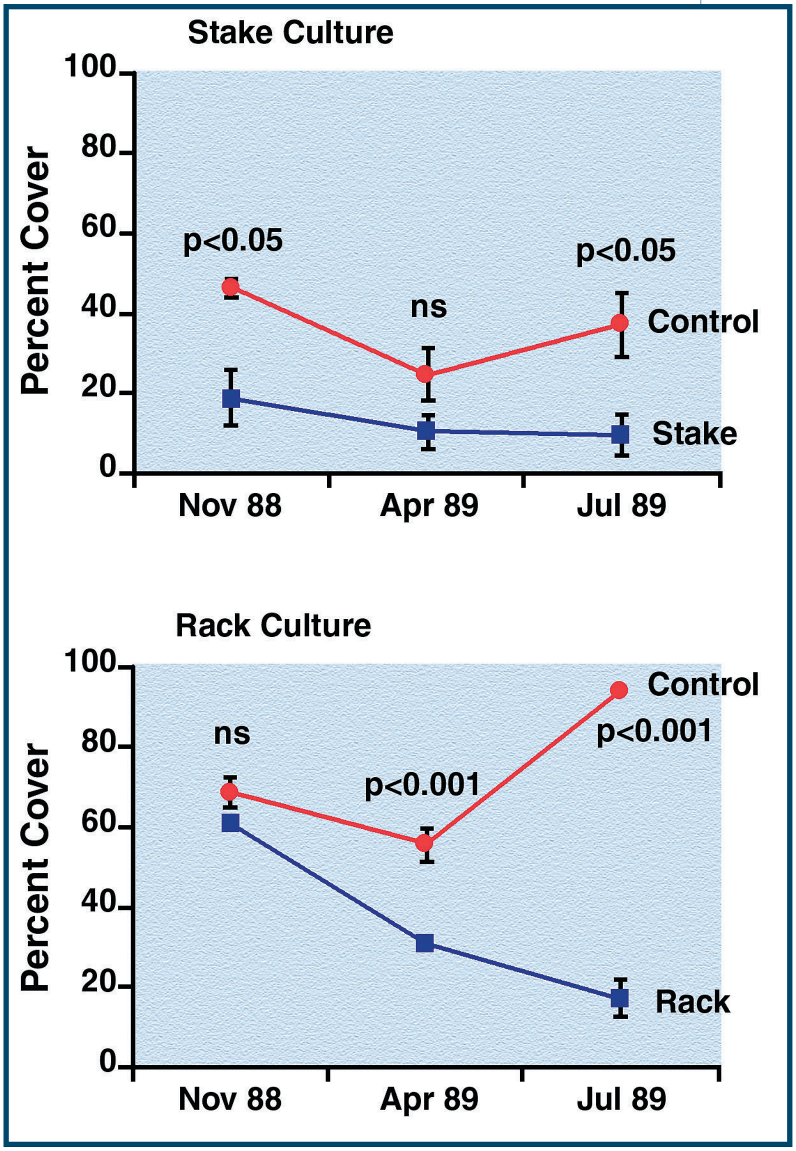


Figure 3.35. Seasonal changes in spatial cover (%) for eelgrass (*Zostera marina*) in experimental oyster cultivation and control plots. Percent cover values indicate the means and standard errors for rack, stake, and control plots over time (November 1988 – July 1989; from Carlton *et al.*, 1990).

within estuarine tideflats that are managed for the commercial production of Pacific oysters on elevated racks and stakes.

Rumrill and Christy (1996) conducted a short-term study of the ecological impacts of Pacific oyster (*Crassostrea gigas*) ground culture on estuarine sediments, infaunal invertebrates, and eelgrass (*Zostera marina*) communities within the South Slough NERR. Experimental plots were established (southwest of Valino Island) with: (a) living oyster cultch (juvenile oysters attached to non-living adult shells), (b) non-living oyster shells, and (c) no treatment (controls). Changes in the composition and particle sizes of sediments were not significant within the sandy mud substrata after a periods of 2.5, 6, and 12 months. Infaunal invertebrate communities within the control, oyster cultch, and shell plots were all dominated by capitellid polychaetes, and they included a diverse assemblage of other polychaetes, burrowing bivalves, nemerteans, cumaceans, and other invertebrates. Gammarid amphipods were also abundant in the control plots.

Annual and seasonal variability in the spatial cover and density of eelgrass was substantial over a period of 2 yrs. Spatial cover and density of eelgrass followed a markedly seasonal pattern in the South Slough estuary with a relatively high abundance of plants in the mid-to-late summer and lower abundance in the winter and early spring. This pattern is typical for beds of *Zostera marina* in the Pacific northwest (Phillips, 1984; Pregnall, 1993; Everett *et al.,* 1995). Annual variation was substantial, and the eelgrass bed underwent a general decrease in spatial cover and density between 1995 and 1996. These observations were consistent with poor development of eelgrass beds during the 1996 growing season at other locations (*i.e.* Yaquina Bay, OR and Willapa Bay, WA) and were coincidental with the large-scale modification of nearshore ocean conditions driven by the 1996 El Niño – Southern Oscillation event throughout the Oregon and Washington coasts. Density of eelgrass plants decreased by 59.4% over a period of 75 days in the oyster treatment plots, compared with only a 28.8% reduction in the control plots (Rumrill and Christy, 1996). Eelgrass beds increased slightly in spatial cover (+10.2%) within the higher intertidal (shoreward) regions of the control area, while at the same time they decreased by 70.7% at the high elevations within the oyster treatment area. Spatial cover of *Z. marina* also declined at lower intertidal elevations within both the control (-25.4% cover) and oyster treatment plots (-36.7% cover). These data suggest that oyster ground culture activities may have a substantial negative impact on eelgrass spatial cover, particularly at the higher intertidal elevations near the upper limit of eelgrass distribution.

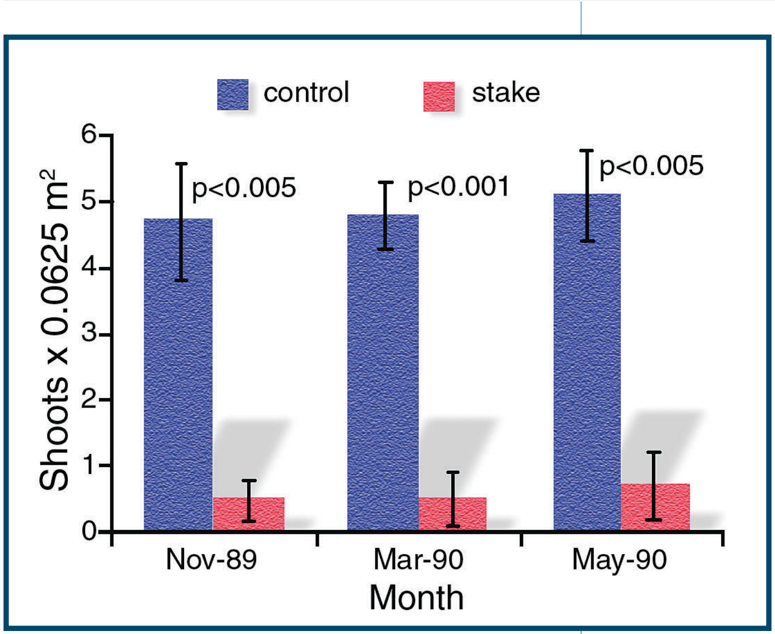
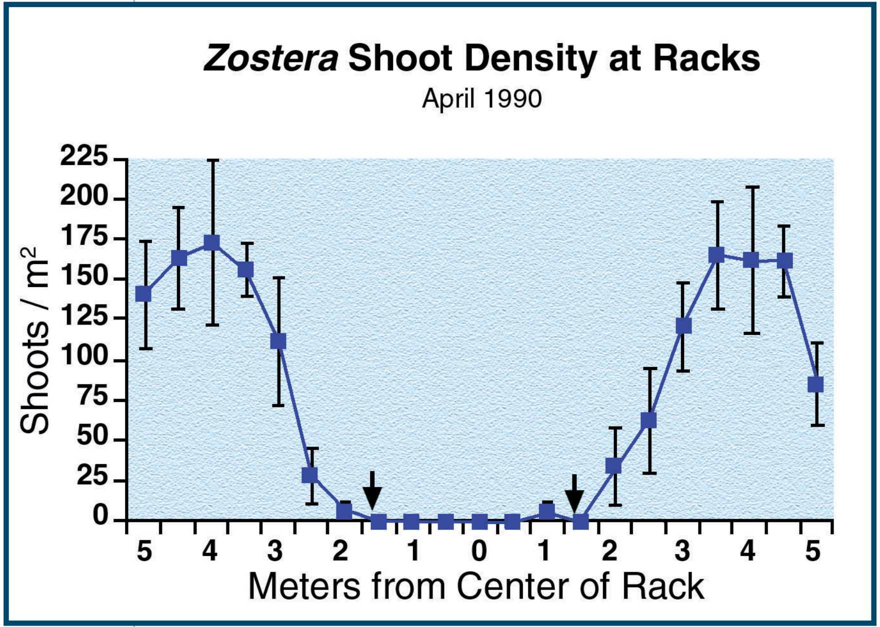


Figure 3.36. Density of *Zostera marina* shoots in experimental oyster stake plots (Year 1). Shoot densities indicate means and standard errors over time (November 1989 – May 1990; from Carlton *et al.*, 1991).

Figure 3.37. Density of *Zostera marina* shoots in experimental oyster rack plots (April 1990), 15 months after initiation of rack cultures. Shoot densities indicate means and standard errors. (Arrows indicate edges of racks; from Carlton *et al.*, 1991).



3.5.3 Regrowth and Recovery of Eelgrass Communities

Native eelgrass (*Zostera marina*) is widely recognized to serve several important ecological functions in Pacific Nortwest estuaries (Phillips, 1984; Simenstad, 1994). Meadows of *Z. marina* support diverse assemblages of infaunal and epifaunal invertebrates (Simenstad *et al.*, 1988; Pregnall, 1993) by: (a) provision of physical structure in the water column above shallow subtidal and intertidal flats (Orth and Heck, 1980; Heck and Thoman, 1984; Orth *et al.*, 1984; Peterson *et al.*, 1984; Edgar, 1990), (b) localized modification of water flow, sediment deposition and stability (Orth 1977; Harlin *et al.*, 1982; Fonseca *et al.*, 1983; Fonseca and Fisher, 1986), (c) enhancement of nutrient exchange between sediments and the water column (McRoy *et al.*, 1972; Hemminga *et al.*, 1991), and (d) creation of large quantities of organic matter that serve as living and detrital food sources for estuarine consumers (McConnaughey and McRoy, 1979; Bach *et al.*, 1986; Nienhuis and Groenendijk, 1986). Western black brant geese (*Branta bernicla nigricans*) have a winter diet that consists of 85% eelgrass (Cottam *et al.*, 1944; Cottam and Munro, 1954) and it appears that greater scaup (*Aythya marila*), a duck locally abundant in Oregon in the fall, also utilize eelgrass in their diets (Cottam *et al.*, 1944). In addition, wigeon (*Anas penelope*) and teal (*Anas crecca*) utilize eelgrass in the fall and winter (Tubbs and Tubbs, 1983). Simenstad and Wissmar (1985) determined that eelgrass provides the basis for the food web for the out-migrating juvenile chum salmon in Hood Canal, WA. It is known that Pacific herring (*Clupea harengus*) spawn on eelgrass blades (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 (Summerson and Peterson, 1984; Leber, 1985; Fredette *et al.*, 1990).

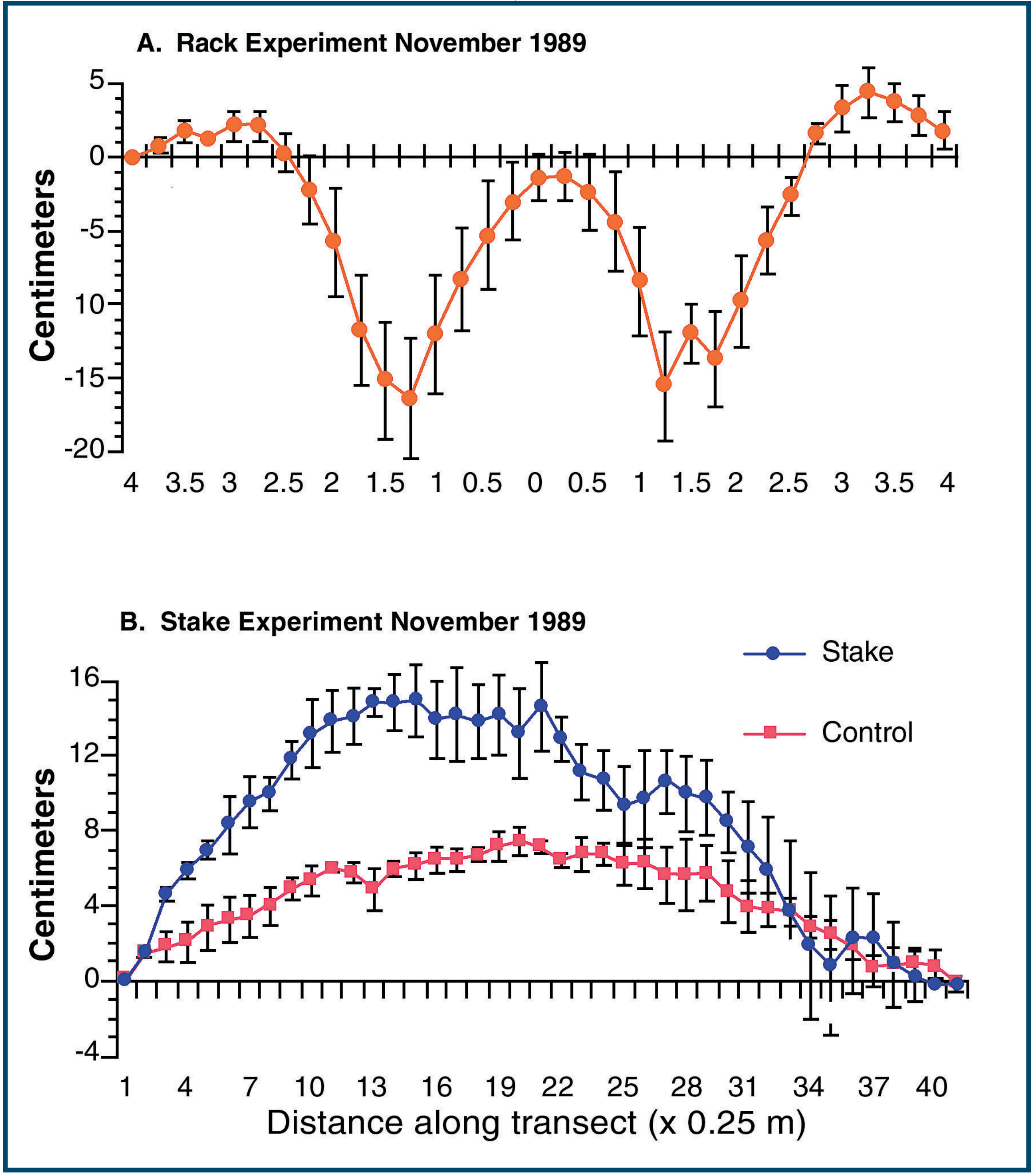


Figure 3.38. Contrasting effects of rack and stake oyster culture techniques on sediment surface topography within the South Slough. A. Average surface topographical relief of rack plots (August 1989). B. Average surface topographical relief of stake plots (November 1989). Vertical bars indicate ± 1 SE; from Carlton *et al.*, 1990.

Experimental work was conducted by Pregnall (1993) within the South Slough National Estuarine Research Reserve in order to: (a) examine the impacts of commercial oyster culture on macrophytes and populations of estuarine fish and invertebrates, and (b) monitor recovery of lost habitat values following the removal of stake-cultured Pacific oysters (*Crassostrea gigas*). In addition, the study also investigated acceleration of habitat recovery by experimental transplants of eelgrass turions (shoot and rhizomes of *Z. marina*). Densities of eelgrass shoots, nutrient levels, sediment porosity and grain size, and infaunal and epibenthic species were all analyzed within four control plots and four experimental oyster plots prior to the removal of oysters. These parameters were monitored immediately after

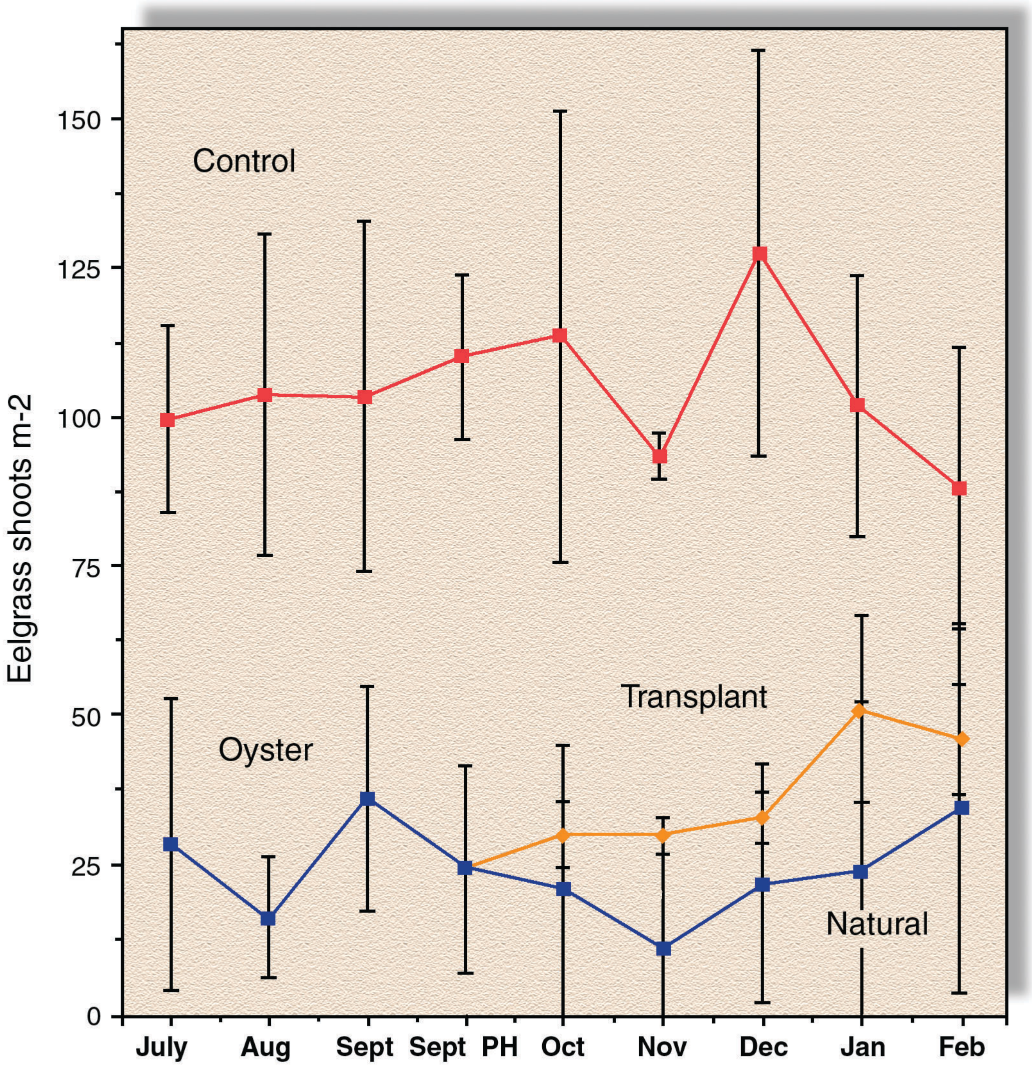


Figure 3.39. Density of eelgrass (*Z. marina*) within experimental oyster cultivation and control plots (July 1992 - February 1993) near Ferrie Head, South Slough NERR. Oyster removal occurred in September 1992 (PH: postharvest). Eelgrass was transplanted into 2 plots (Transplant); the remaining 2 plots were left to recover naturally (Natural; from Pregnall, 1993).

oyster harvests within four control plots, two experimental *Z. marina* transplant plots, and two experimental plots that were left to revegetate naturally (Figure 3.39).

Abundances of eelgrass, Dungeness crab (*Cancer magister*), macrofauna burrows and total infaunal species were significantly lower in the experimental oyster plots compared to adjacent control areas. In particular, eelgrass shoots were reduced by 75% in the oyster plots (Figure 3.39). In contrast, oyster plots supported significantly greater biomass of macrofaunal invertebrates and significantly smaller individuals of infaunal bivalves (*Cryptomya californica*). Pregnall (1993) also observed that oyster beds support large numbers of mobile epibenthic species including *Cancer productus, Hemigrapsus* spp., sculpins and blennies. Following the removal of oysters, there was a significant decline in sediment porosity and fine grain sized sediments in the oyster plots. This evidence suggests that oyster beds serve as depositional environments, and that harvest of oysters may release an episodic pulse of sediments into the estuary. Large numbers of small bivalves recruited into the recovery plots, however the population of large mobile epibenthic invertebrates disappeared following oyster removal. Five months after the removal of oysters, both transplant and natural recovery plots still exhibited significantly lower densities of eelgrass shoots compared to control plots (Figure 3.39). Eelgrass transplant plots, however, recovered at a faster rate than the plots left to recover naturally. Rates of eelgrass recovery are directly proportional to the initial density of eelgrass shoots that existed prior to the onset of recovery phase. Vegetative propagation from surrounding eelgrass plants was responsible for the majority of eelgrass recovery rather than propagation by seeds.

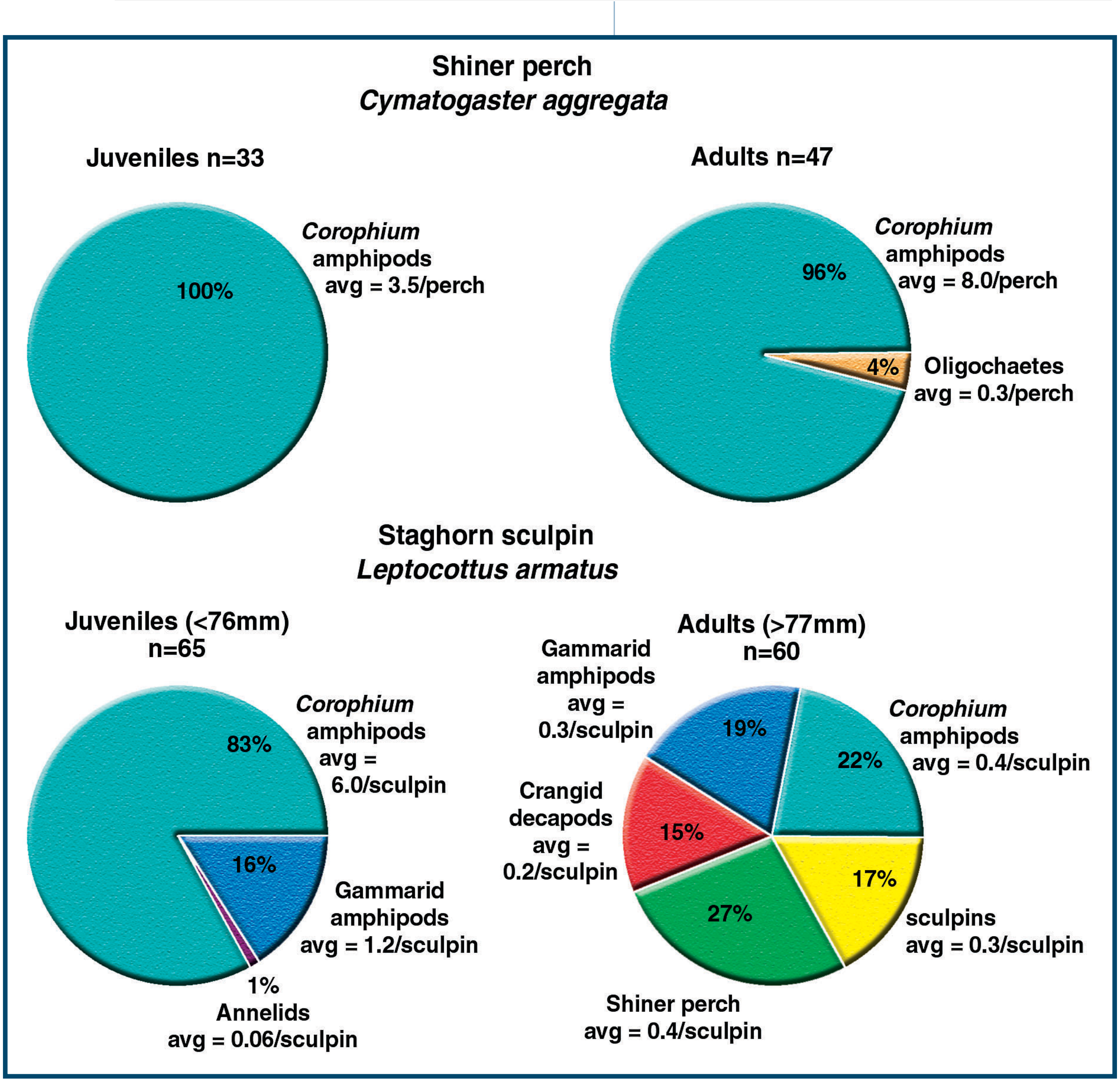


Fig. 3.40. Gut contents of Shiner perch and Staghorn sculpin collected from the Winchester Creek tidal channel, South Slough NERR, OR (adapted from Frank *et al.*, 1990).

Based on the findings of her study, Pregnall (1993) recommended that commercial cultivation of *Crassostrea gigas* be prohibited in areas previously occupied by eelgrass meadows. Pregnall (1993) further recommended that administrative procedures be instituted to review and monitor existing oyster leases on a case-by-case basis in order to determine whether oyster cultivation should be continued. It is clear that further information is necessary to more fully understand the ecological interactions between eelgrass beds and commercial mariculture of *C. gigas*, and to reduce further degradation of eelgrass habitats when granting new mariculture leases within Pacific northwest estuaries.

3.5.4 Diet and Ecological Role of Fish in Estuarine Tidal Channels

The influence of predation by fishes on estuarine community structure has received considerable attention within the South Slough (Posey, 1986; Frank *et al.,* 1990). These studies are particularly appropriate since the estuarine tideflats and channels are utilized as forage areas for diverse communities of marine, estuarine, and anadromous fish (Bottom *et al.,* 1988) and because the soft-sediment habitats support assemblages of benthic invertebrates that provide an essential food source for higher tropic groups. Pacific staghorn sculpin (*Leptocottus armatus*) play a central ecological role as predators of benthic invertebrates and other fishes. In a survey of the diet of *L. armatus* conducted in the Winchester Creek region of the South Slough, nearly 85% of the sculpins examined contained identifiable gut contents (Frank *et al.,* 1990). Prey selection is strongly influenced by sculpin body size. For example, the diet of small sculpins (< 76 mm in length) consisted almost entirely of gammarid amphipods (*Corophium* spp. / 83% and other gammarids / 16%), with the remainder comprised of polychaete annelids (1%; Figure 3.40). In contrast, the diet of large staghorn sculpins is more catholic and includes a diverse selection of *Corophium* spp. (22%), other gammarids (19%), crangid shrimp (15%) shiner perch (27%), and other sculpins (17%). All (100%) of the shiner perch (*Cymatogaster aggregata*) examined contained identifiable gut contents, and both large and small perch preyed almost exclusively upon gammarid amphipods (Figure 3.40). The different age classes of *L. armatus* and *C. aggregata* co-occur in the tidal channels of the South Slough estuary, and it appears that shiner perch compete directly with juvenile staghorn sculpins for available prey resources. Diets were also examined for other resident estuarine fish (Frank *et al.,* 1990) including starry flounder (*Corophium* spp. 100%), prickly sculpin (*Corophium* spp. 87%, other gammarids 13%), and topsmelt (gammarids 45%, mysids 28%, unidentified decapods 27%).

3.6 Introduction and Spread of Non-Indigenous Species

Biological invasions pose a considerable threat to the ecological integrity of the South Slough estuary (Carlton, 1989; Carlton and Geller, 1993; Hewitt, 1993). Frequent disturbance of established marine and estuarine communities by natural events such as seasonal flooding, storm waves, and rockslides continually generate new shoreline habitats that are often initially colonized by opportunistic species (Simenstad *et al.,* 1997). In addition, the establishment of anthropogenic structures (floating docks, piling systems, and the hardening of shorelines with jetties, bulkheads, and rip-rap) presents a collateral suite of sites that are vulnerable to invasion by exotic species (Hewitt, 1993). In some cases, nonindigenous species may successfully invade established communities and slowly displace native species from their natural habitats over periods of years or decades. Human-induced stress and disturbance may further increase the vulnerability of natural habitats and anthropogenic structures to the establishment and spread of invasive species. Exotic invaders and nuisance species may be particularly likely to become established in ecological communities where human activities have pushed native species toward local extinction (Vermeij, 1991). Our understanding of invasions in marine and estuarine ecosystems is poor in comparison with knowledge developed for terrestrial and freshwater systems (Carlton, 1989), but it is generally acknowledged that marine invasions may be widespread and of sufficient magnitude to precipitate profound ecological changes in nearshore communities (Carlton and Geller, 1993).

3.6.1 Extent of Estuarine Invasions by Non-Indigenous Aquatic Species

Oregon's shallow estuaries and protected embayments are particularly susceptible to invasion by non-indigenous species. Commercial mariculture operations have resulted in numerous deliberate and inadvertent introductions of exotic species into tidal channels and tideflat communities. Moreover, intensive human settlement and shoreline development in estuaries that support deep-draft ship traffic (Coos Bay, Yaquina Bay, Columbia River) have been coupled with global increases in ship traffic, reductions in transoceanic transit times, and chronic introductions of non-native species over the past century. The increased frequency of non-native introductions associated with ballast water transport has created many opportunities for exotic species to invade new ecological niches maintained by frequent disturbance and anthropogenic activities (Carlton and Geller, 1993).

Cargo ships have used ballast water regularly in their transport of freight into the Coos estuary since the 1880's. Docked ships typically draw ambient marine or estuarine water into their ballast tanks and floodable compartments in order to maintain stability, limit hull stress, and provide effective steerage. Ballast water is discharged while underway and at subsequent ports-of-call as cargo is off-loaded and new freight is taken on. Ballast water carried within cargo ships contains a diverse variety of holoplanktonic organisms (species that spend their entire lives in the water column) and meroplanktonic organisms (species that spend the larval period of their life cycle in the water column and the adult phase on the bottom). These assemblages of planktonic organisms are entrained by the vessel and then discharged into the tidal waters of Coos Bay after days or weeks of transport from their point of origin thousands of kilometers away. Carlton and Geller (1993) examined the ballast water from 159 cargo vessels docked in Coos Bay during 1986-1991, and they found 367 exotic taxa that had survived in ballast tanks after transoceanic trips from Japan (11 to 21 days). All major and minor phyla were represented in the ballast water assemblages, including 16 animal and 3 protist phyla and 3 plant divisions. More importantly, the assemblages also contained members of all major marine trophic groups including carnivores, herbivores, omnivores, deposit-feeders, scavengers, suspension feeders, primary producers, and parasites. These species are typically found in an array of infaunal, soft and hard-bottom epifaunal epibiotic and planktonic habitats. Future investigations may shed important light on the ecological consequences of these potentially invasive species.

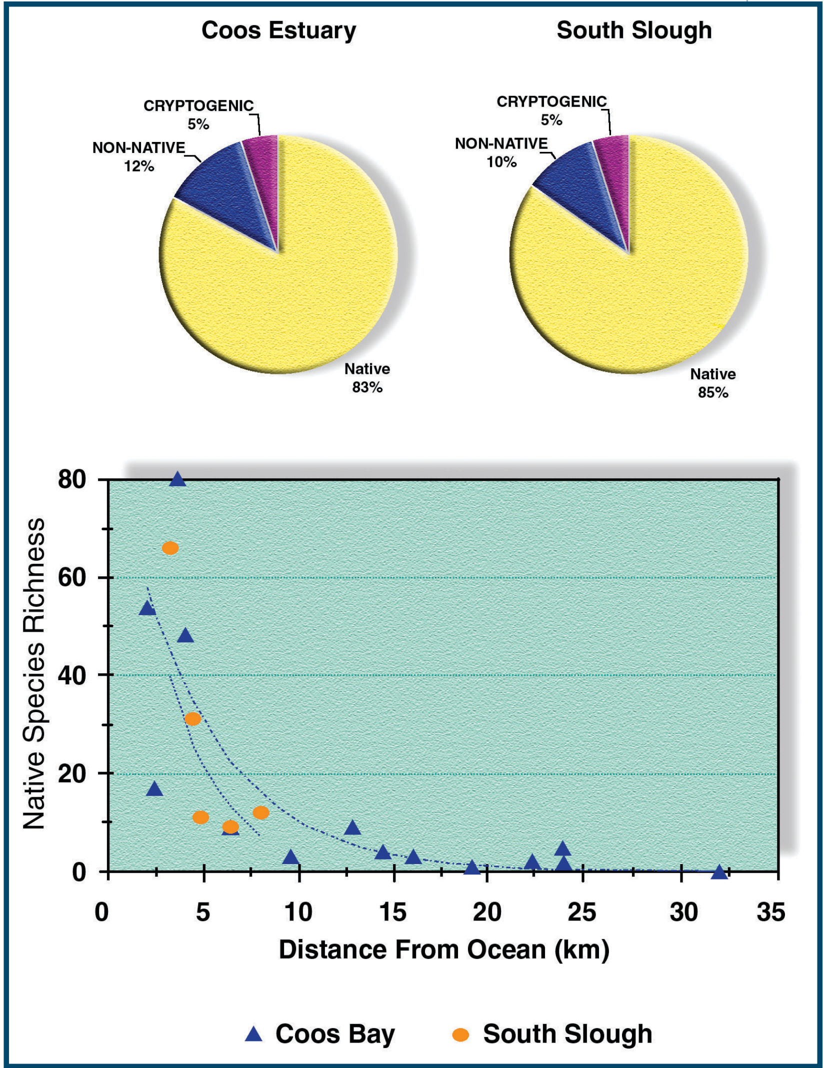


Figure 3.41. Similarity in the relative composition of native, non-native, and cryptogenic species within the Coos estuary and South Slough, OR. Species richness of native aquatic invertebrates declines rapidly with increasing distance up the estuary (away from the Pacific Ocean; adapted from Hewitt, 1993).

Over 50 species of non-indigenous marine and estuarine organisms have become established within the tidal waters of the South Slough NERR (Carlton, 1989; 2005; Hewitt, 1993; Rumrill, pers. observations; Table 3.15). The diverse assemblage of non-native species represents several higher level taxonomic groups including algae and aquatic angiosperm plants, sponges, bryozoans, cnidarians, annelids (polychaetes), molluscs (bivalves and gastropods), arthropods (decapods, isopods, and amphipods), and fish. In particular, dense beds of the Japanese eelgrass (*Zostera japonica*) have become firmly established in the upper intertidal zone throughout the South Slough where they dominate the mudflats, alter sediment deposition, and result in dramatic changes in the composition of infaunal invertebrate communities (Posey, 1988; Posey and Rudy, 1987). The Atlantic sponge *Halichondria bowerbankia* is very common on a variety of hard substrata, and colonies of the introduced bryozoans *Bugula* spp., *Conopeum tenuissimum*, and *Schizoporella unicornis* are abundant on pilings and oyster shells. Colonies of the compound tunicates *Diplosoma mitsakurii, Botryllus* spp. and *Botrylloides* spp. are also common on docks and pilings in the northern region of the estuary, and the non-native polychaetes *Polydora cornuta, Heteromastus filiformis, Streblospio benedicti*, and *Pseudopolydora kempi* are among the most abundant invertebrates in the South Slough.

Hewitt (1993) measured the occurrence of native, non-indigenous, and cryptogenic epifouling species along transects placed on floating docks, piers, and pilings in the Coos estuary and South Slough. Relative proportions of these three categories of species were virtually identical within the primary arm of greater Coos estuary and the smaller South Slough sub-system (Figure 3.41). For example, out

Table 3.15. List of introduced estuarine species within the South Slough NERR, OR (from Jefferts, 1977; Rudy and Rudy, 1983; Posey, 1985; Posey and Rudy, 1986; Carlton, 1989; 2005; Rumrill, 1991; Hewitt, 1993; Rumrill and Christy, 1996).

Species	Origin	Mechanism of Introduction
Porifera		
Halichondria bowerbanki	Atlantic	oyster industry
Cliona sp.	unknown	oyster industry
Cnidaria		
Diadumene lineata	Japan or Atlantic	oyster industry, ships
Nematostella vectensis	Atlantic	oyster industry, ships
Tubularia crocea	NW Atlantic	oyster industry, ships
Ectoprocta		
Bugula neritina	Europe	oyster industry, ships
Conopeum tenuissimum	NW Atlantic	oyster industry
Cryptosula pallasiana	Atlantic?	oyster industry, ships
Schizoporella unicornis	Japan	oyster industry
Watersipora subtorquata	Southern California	ships or intentional
Entoprocta		
Bowerbankia gracilis	Atlantic?	oyster industry, ships
Annelida		
Heteromastus filiformis	Atlantic	oyster industry
Polydora cornuta	Atlantic	oyster industry
Streblospio benedicti	Atlantic	oyster industry
Pseudopolydora kempi	Japan	oyster industry, ships
Neanthes succinea	W Atlantic	oyster industry
Ophelina acuminata	N Atlantic	
Eteone longa	NW Pacific, N Atlantic, Arctic	oyster industry, ships
Capitellidae spp.	Atlantic, Japan	oyster industry, ships
Spionidae spp.	Atlantic, Japan	oyster industry, ships
Phyllodocidae spp.	Atlantic, Japan	oyster industry, ships
Mollusca		
Crassostrea gigas	Japan	oyster industry
Mya arenaria	Atlantic	oyster industry, intentional
Nuttallia obscurata	Japan Korea	ships
Venerupis philippinarum	Japan	intentional
Ovatella myosotis	Atlantic	oyster industry, ships
Tenellia adspersa	N Atlantic	oyster industry
Crustacea		
Melita nitida	Atlantic	oyster industry
Corophium acherusicum	Atlantic	oyster industry, ships
Amphithoe valida	Atlantic	oyster industry
Jassa marmorata	Atlantic, Japan	oyster industry, ships
Eobrolgus spinosus	Atlantic	oyster industry
Grandidierella japonica	Japan	oyster industry
Limnoria tripunctata	Atlantic?	ships
Sphaeroma quoianum	New Zealand	ships, wood, styrofoam
Sinelobus sp.	circumtropic	oyster industry, ships
Leptochelia dubia	N Atlantic	oyster industry, ships
Nippoleucon hinumensis	Japan	ships
Balanus improvisus	W Atlantic	oyster industry
Rhithropanopeus harrisii	Atlantic	oyster industry, ships
Carcinus maenas	Europe	larval drift
Urochordata		
Botrylloides violaceus	Japan	oyster industry
Botryllus schlosseri	Europe	oyster industry, ships
Molgula manhattensis	NE Atlantic	oyster industry, ships
Diplosoma mitsakurii	Japan	oyster industry, ships
Styela clava	Japan	ships
Chordata		
Alosa sapidissima	Altantic	intentional
Morone saxatilis	Atlantic	intentional
Gambusia affinis	E N America	intentional
Phaeophyta		
Sargassum muticum	Japan	oyster industry
Angiospermae		
Zostera japonica	Japan	oyster industry
Spergularia salina	Europe	unknown
Spartina alterniflora	Atlantic	marsh restoration

of 101 epifouling organisms observed in the Coos estuary, 83% were considered as native to the Pacific northwest coast, 12% were non-native species, and 5% were cryptogenic in origin. Similarly, a total of 78 epifouling organisms were identified in the South Slough, of which 85% were native, 10% were non-native, and 5% were cryptogenic.

Distinctly different regions of the greater Coos estuary exhibit highly comparable levels of beta diversity (within-habitats along the estuarine gradient), despite chronic input of planktonic larval stages from potentially invasive species in ballast water discharged into the Coos Bay navigational channel (Carlton and Geller, 1993). Ballast water from large cargo vessels is not discharged directly into the South Slough. It is possible that larvae contained within ballast water released into the upper and mid regions of the Coos estuary move to the lower tidal basin and eventually enter South Slough. Alternatively, it is also possible that populations of invasive species established in the Coos estuary produce additional (2^{nd} generation) larvae that are retained within the tidal waters and eventually settle in the South Slough. Finally, in is important to note that the majority of non-indigenous species observed within the South Slough by Hewitt (1993) were probably not introduced via large ships, but rather they represent a sub-set of the non-indigenous species assemblage associated with: (a) commercial oyster cultivation practices, and (b) spread from established populations on floating docks, public marinas, and shoreline port facilities. In any case, the high proportion of non-indigenous species within the South Slough estuary is most likely a consequence of some combination of the long history of commercial oyster mariculture, close proximity of the Charleston boat basin, and ongoing operation of an industrialized shipping port in commingled tidal waters.

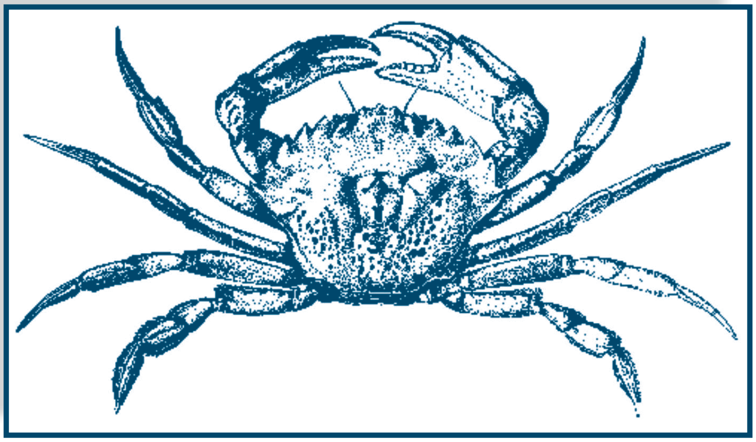


Figure 3.42. The European green crab (*Carcinus maenas*) was recently introduced into Coos Bay and the South Slough estuary (1996), and can potentially colonize all of Oregon's estuaries and other regions of the Pacific northwest coast. Green crabs first arrived in San Francisco Bay in 1989 and then rapidly expanded north into Bodega Bay and Humboldt Bay, CA, and to Yaquina Bay, OR and Willapa Bay, WA (1997-99).

Hewitt (1993) also conducted a case study of the spread of a non-native species within the Coos estuary. The compound tunicate (*Botrylloides violaceus*; imported from Japan in association with commercial maricultre of Pacific oysters) was introduced into the upper region of the Coos estuary (Isthmus Slough) during relocation in 1991 of a floating dock from the shoreline of the South Slough (Joe Ney Slough). Colonies of *B. violaceus* produce large, short-lived lecithotrophic larvae that typically settle on hard surfaces within 10 hrs after release (Saito *et al.,* 1981; Boyd *et al.,* 1990). Colonies of *B. violaceus* were observed along the shoreline of Coos Bay in 1992, and they became established in Pony Slough after a period of 3 years. These observations provide indirect evidence that *B. violaceus* spread through the upper and mid region of the estuary at a rate of 2 km yr^{-1}, and they imply a potential mechanism for colonization into the South Slough by non-indigenous species that become established in other parts of the estuary.

Species richness of native estuarine invertebrates decreases rapidly along the estuarine gradient of the Coos estuary and South Slough (Hewitt, 1993; Figure 3.41). Native species richness is high (66-80 species) in the marine-dominated waters near the mouth of the estuary but declines to about 10 species at a distance of 8-10 km from the ocean. Non-native estuarine species that are associated with the oldest and most obscure introduction events (fouling on wooden ship hulls) appear to have spread throughout the Coos estuary on docks and piers (Hewitt, 1993). However, these species make up only a minor proportion of the fauna in South Slough where wood substrata are limited to old log pilings, fallen trees, and woody debris (branches, rootwads).

Overharvesting of estuarine fish and shellfish populations has been a management problem in the Pacific northwest for over a century. By the late 1890's it became profitable to supplement depleted native oyster beds by transplanting East Coast oysters. These deliberate introductions of the Eastern oyster (*Crassostrea virginica*) and Japanese oyster (*Crassostrea gigas*) for mariculture purposes have facilitated the inadvertant introduction of at least 35 exotic species into the South Slough estuary, OR (Carlton, 1989) and at least 25 other species of plants and macroinvertebrates into Willapa Bay, WA (Hedgepeth and Obrebski, 1981). Oyster mariculture operations create thousands of acreas of persistent exotic biogenic reef-like substrata that are colonized by a mixture of native estuarine organisms and opportunistic nonindigenous species. It is estimated that at least 30% of the benthic estuarine organisms in Yaquina Bay, OR are introduced species (Chapman, pers. observ.), and Zipperer (1996) has recently estimated that 40 to 81% of the total density (and 28 to 39% of all species) of benthic macroinvertebrates found in Willapa Bay, WA may be exotic. An introduced Japanese clam (*Corbicula manilensis*) now dominates the tidal freshwater and brackish estuarine benthic communities of the Columbia River estuary. A pelagic copepod (*Pseudodiaptomus inopinus*) introduced into the Columbia River estuary during the last decade is now one of the most common zooplankton species there and elsewhere along the Oregon coast (Cordell *et al.*, 1992). These copepods appear to be a common prey of the introduced American shad (*Alosa sapidissima*) which have increased dramatically in abundance over the last century since they were intentionally introduced to the west coast. The ecological impacts of these invasive species have not been evaluated and their spread among Oregon's estuaries has not been monitored on a systematic basis.

3.6.2 Colonization of Tideflats by European Green Crabs

The European green crab (*Carcinus maenas*; Figure 3.42) was recently introduced into Coos Bay and the South Slough estuary, and this species has the potential to rapidly colonize all of Oregon's estuaries and other regions of the Pacific northwest coast (Yamada, 2002). Green crabs are native to Europe, but they have been introduced to Australia and South Africa, and inhabit coastal regions along much of the Atlantic seaboard of the United States. Green crabs first arrived in San Francisco Bay in 1989 and then rapidly expanded northward into Bodega Bay and Humboldt Bay, CA. The first green crabs were found in Coos Bay in 1996, with subsequent discoveries in 1997-99 in Yaquina Bay and Tillamook Bay, OR, Willapa Bay, WA, and along the shoreline of Vancouver Island, BC (Yamada, 2000). Green crabs are voracious predators that feed on mussels, oysters, crabs, shrimp, small fish, and a variety of other marine organisms, and there are considerable concerns regarding impacts on local commercial and recreational fisheries through direct predation and indirect competition for prey resources.

3.6.3 Spread and Community Alteration by Japanese Eelgrass

Dense beds of the Japanese eelgrass (*Zostera japonica*) have colonized the mid intertidal zone of most Oregon estuaries, and invasion by this species has changed thousands of acres of mudflat habitat into rooted aquatic vegetation with concomitant alterations of estuarine infaunal communities (Posey, 1988). Viable ramets of *Z. japonica* were probably introduced into the Pacific northwest region from Japan in association with commercial oyster cultivation activities (Harrison, 1976), and *Z. japonica* was first observed in Willapa Bay, WA in 1957 (Harrison and Bigley, 1982).

Survey records from the Coos estuary indicate that *Zostera japonica* has probably been established within the South Slough NERR since 1970 or earlier (Posey and Rudy, 1987; Posey, 1988). The distribution of *Z. japonica* was patchy in the upper reaches of the South Slough in the early 1970's, and the invasive eelgrass spread to the middle region of the estuary by 1987. By the early 1980's *Z. japonica* had also become established in the northern region of South Slough, and dense beds (sometimes with over 100% spatial cover) commonly occurred in the mid intertidal zone between elevations of +0.6 to +1.0 m above MLLW (Figure 3.43).

Knowledge of the local invasion history and spatial distribution of *Zostera japonica* allowed for assessments of the immediate and long-term ecological impacts of colonization on the tideflat environment (Posey and Rudy, 1987; Posey, 1988). In addition, transplant experiments were carried out to develop empirical evidence of the impact of *Z. japonica* on estuarine invertebrate communities. Comparisons of benthic infauna between *Z. japonica* patches and unvegetated mudflats were made at Ferrie Marsh (old eelgrass patches), Portside Flats (intermediate patch age), and Valino Island (recently-colonized) within the marine-dominated to lower mesohaline region of the South Slough estuary. Sediment particle sizes and organic content differed significantly between the *Zostera japonica* beds and unvegetated areas less than 1 m away. Mean sediment particle size was generally smaller within *Z. japonica* patches, and the concentra-

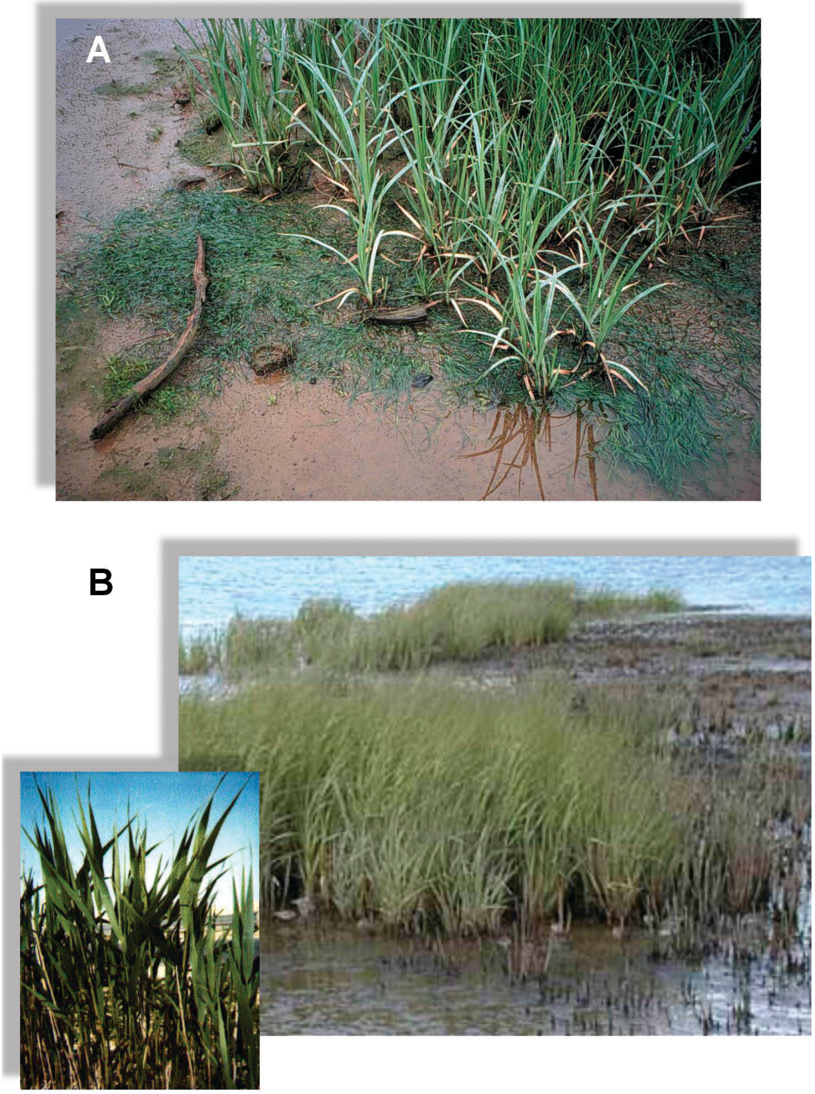


Figure 3.43. Introduced plants within Pacific northwest estuaries. A) The introduced Japanese eelgrass (*Zostera japonica*) occurs in the mid intertidal region where it colonizes previously unvegetated mudflats. Small beds of *Z. japonica* are shown here at the base of Lyngbye sedge (*Carex lyngbyei*) at an elevation of +1.5 m above NAVD within the experimental Kunz marsh restoration site, South Slough NERR, OR. B) Atlantic smooth cordgrass (*Spartina alterniflora*) colonizes unvegetated mudflats in Willapa Bay, WA.

tion of volatile organic material was elevated by 224% in the non-native eelgrass compared to adjacent unvegetated areas.

Colonization of the mid intertidal mudflats by *Zostera japonica* resulted in significant changes to both the species composition and abundance of infaunal invertebrate communities (Figure 3.44). Species richness was elevated by about 16% within the *Z. japonica* patches where an average of 44 taxa of invertebrates were identified compared to a mean of 38 species in the unvegetated sites. The trend toward higher species richness in *Z. japonica* patches was particularly evident in the old and intermediate-aged eelgrass beds (Ferrie Marsh and Portside Flats). Increased species richness within *Z. japonica* patches was generally caused by the infrequent occurrence of invertebrates normally found in the low intertidal zone and subtidal channels.

Higher densities of several infaunal invertebrates were also observed in the *Zostera japonica* patches within the South Slough (Posey, 1988). In particular, three species of tube-dwelling spionid polychaetes (*Pygospio elegans, Streblospio benedicti, Pseudopolydora kempi*), a free-living burrowing polychaete (*Eteone californica*), sedentary and mobile arthropods (*Corophium* spp., *Cumella vulgaris)*, and diptera larvae were more abundant in the non-native eelgrass at the oldest Ferrie Marsh site (Figure 3.44). Less obvious patterns of elevated infaunal abundance occurred at the intermediate-age Portside Flat and recently-colonized Valino Island sites. Community responses within the *Z. japonica* transplant plots were generally similar to those in recently-colonized eelgrass patches.

The ecological role of the *Zostera japonica* canopy as a refuge from epibenthic predators (primarily staghorn sculpin, *Leptocottus armatus*; shiner perch, *Cymatogaster aggregata*; Dungeness crab, *Cancer magister*) was investigated in a series of cage experiments (Javier, 1987). Four species of spionid polychaetes (*Pygospio elegans, Streblospio benedicti, Pseudopolydora kempi, Boccardia truncata*) were common in *Z. japonica* beds, and exclusion of predators resulted in an increase in the abundance of these polychaetes in the cage treatment plots relative to un-caged controls. Conversely, Rumrill and Kerns (1991) observed settlement of Dungeness crab megalopa larvae within dense beds of *Z. japonica* throughout the South Slough estuary, within artificial eelgrass beds maintained in the laboratory, and in caged eelgrass beds in the field at Valino Island. Settlement and recruitment of early juvenile *C. magister* in the mid intertidal zone (at higher elevations than normal) leaves them exposed for relatively long periods at low tide where they are presumably subject to heating, desiccation, and predation by crows and seagulls. Results from these manipulative experiments suggest that dense beds of *Z. japonica* modify the intertidal mudflats and serve a refuge role for some species (polychaetes) but may enhance mortality for others (juvenile crabs).

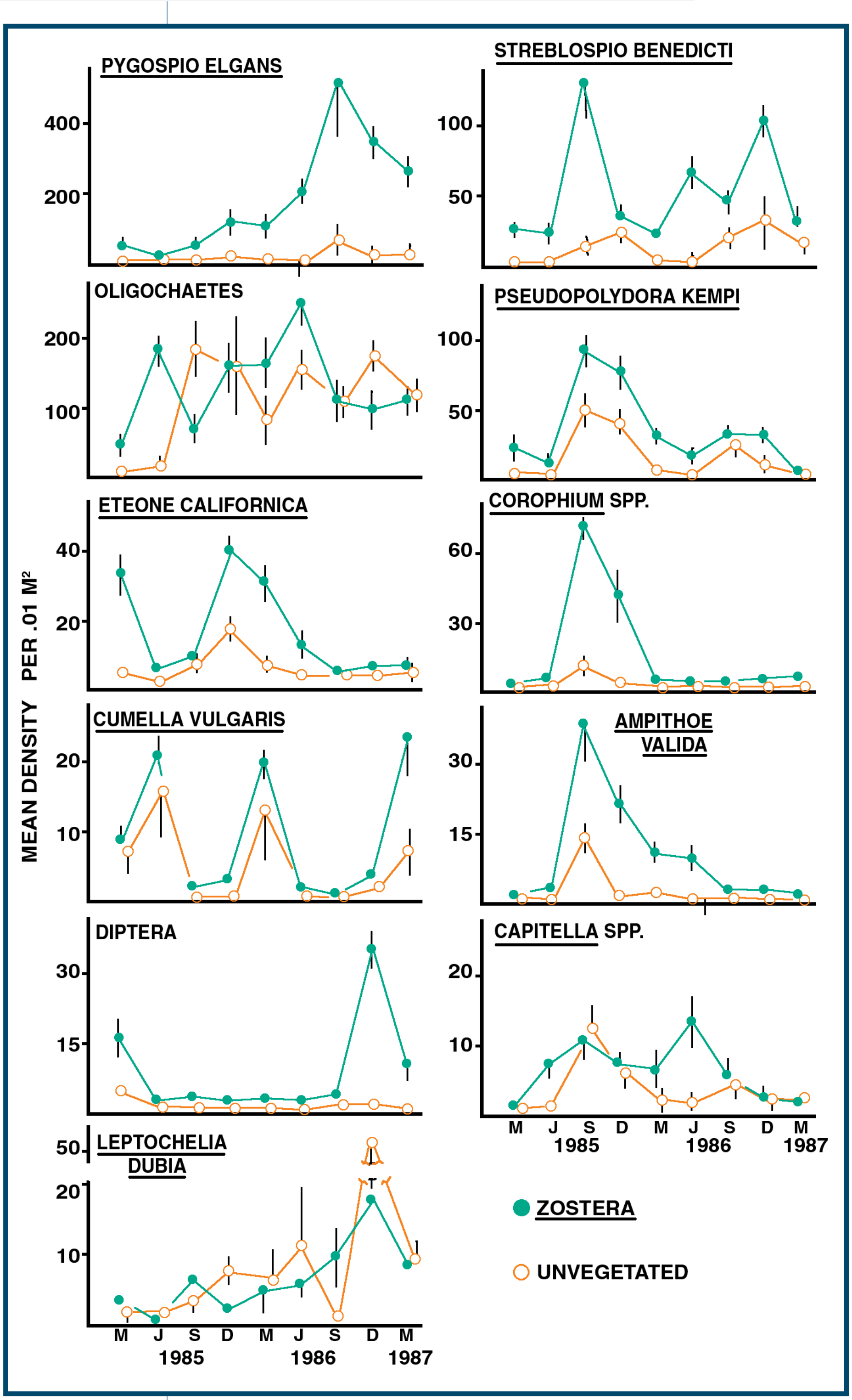


Figure 3.44. Response of infaunal invertebrate community to colonization by Japanese eelgrass (*Zostera japonica*) in the South Slough NERR, Ferrie marsh (from Posey and Rudy, 1987).

Mid intertidal beds of *Zostera japonica* currently occupy extensive areas of previously unvegetated mudflats within the South Slough. Continued spread of *Z. japonica* over the past 30+ years has resulted in expansion of the spatial cover of intertidal vegetation, elevated plant densities, increased above-ground and below-ground biomass, and accumulation of fine sediments throughout the South Slough and Coos estuary. Undoubtedly, there have been additional changes to composition of invertebrate communities within the non-native eelgrass beds over the last 15 years since the studies by Posey and Rudy (1987) and Posey (1988). Continued spread of *Zostera japonica* precipitates changes to the intertidal community that are consistent with those observed for native seagrass beds (Williams and Heck, 2001), including modification of local tidal currents, increased particle retention times and filtration, enhanced sediment deposition and accumulation of detritus, increased species richness and density of suspension-feeding invertebrates, and overall enhancement of habitat complexity for motile epifauna and fish (Grady, 1981; Nelson, 1981; Phillips, 1984; Eckman, 1984; Peterson *et al.,* 1984; Fonseca *et al.,* 1998). Moreover, the newly-established system of subsurface roots and rhizomes of *Z. japonica* also function to stabilize the unconsolidated sediments and may eventually lead to the buildup of sediments immediately below the intertidal marshes. These modifications to the previously unvegetated mudflats are ecological consequences of an unintentional anthropogenic disturbance. Elucidation of the net ecological impacts of colonization by *Z. japonica* on estuarine communities within the South Slough (negative, neutral, or beneficial) remains to be determined.

3.6.4 Future Management of Non-Indigenous Species in the South Slough Estuary

Introduction of Atlantic smooth cordgrass (*Spartina alterniflora*) is of particular concern for future management of the South Slough estuary. Atlantic smooth cordgrass first arrived in Willapa Bay, WA over a century ago, and the species is spreading rapidly in previously unvegetated tidflats where the tall stands of emergent plants accelerate sediment deposition and the buildup of mudflats (Figure 3.43). Invasive expansion of *S. alterniflora* has been documented in several Pacific northwest estuaries including Grays Harbor, Willapa Bay, Puget Sound, and the Siuslaw estuary in Oregon (Mumford *et al.,* 1991). In addition, a small patch of *S. alterniflora* was recently discovered (2005) in a salt marsh restoration site (Barview Wayside) located at the mouth of the Sough Slough estuary. Problems posed by *S. alterniflora* are especially acute in Willapa Bay where over 10 km^2 of intertidal mudflats were covered in 1989. It is estimated that in the absence of active management control measures up to half of the mudflats in Willapa Bay will be converted to elevated salt marsh over the next 20 years (Wolf, 1993). Once established, *Spartina* has numerous direct and indirect impacts (Mumford *et al.,* 1991) including direct displacement of native plants (such as native eelgrass *Zostera marina*; Wyllie *et al.,* 1994). Populations of benthic microflora and invertebrates are greatly reduced within *Spartina* beds, which may lead to the larger-scale disruption of estuarine food webs. Over time, it is possible that invasion by *Spartina* could alter the food web of an entire estuary by reducing nutrient availability, increasing Biological Oxygen Demand (BOD) and contributing excessive amounts of organic material into the detrital food web. Large-scale patches of *Spartina* also trap sediments and function to convert large areas of mid-intertidal flats, resulting in the loss of tidal habitat in a process equivalent to that caused by diking and draining for agricultural purposes. Patches of *S. alterniflora* result in increased sedimentation in some parts of the estuary and reduced sediments in other regions, thereby disrupting natural processes of erosion and deposition on the scale of the entire tidal basin.

Estuarine ecosystems can be subject to chronic and incremental biological stress resulting from successive invasions by non-indigenous species, and from catastrophic population explosions of non-native species. These biological agents can have substantial impacts on populations of native species (Race, 1982), community structure (Nichols *et al.,* 1990) ecosystem functions (Nichols, 1985), and harvesting of shellfish (Bernard, 1969). Non-indigenous species are currently introduced into the South Slough estuarine ecosystem at the rate of one new species per year (Carlton, 2001). Prediction of the ecological responses of the South Slough estuarine communities to continued introductions of non-indigenous species, and development of appropriately-scaled management approaches, is not a trivial process. For example, Japanese eelgrass (*Zostera japonica*) is provided the same habitat value as native eelgrass (*Z. marina*) by some regulatory agencies in the Pacific northwest region despite substanial differences in plant morphology and distribution in the estuarine intertidal zone. Many non-indigenous species (*i.e.* Pacific oysters *Crassostrea gigas*, soft-shell clams *Mya arenaria*, striped bass *Roccus saxatilis*, and American shad *Alosa sapidissima*) have become widely accepted as Valued Ecological Components (VECs) of the coastal ecosystems. Commercial oyster operations have provided a livelihood for generations of local mariculture farmers, and striped bass and American shad support a valuable recreational fishery. Other aquatic nuisance species, however, have detrimental effects on populations of native species through direct competition for space and food. Ecological engineering species (such as *Spartina* spp., *Zostera japonica*, and *Crassostrea gigas*) are of such importance that they create distinct habitat types and may alter entire estuarine communities. Yet even these species can have beneficial effects, including the provision of stabilized habitat for the development of diverse communities as well as a source of prey items for native fish and wildlife. Other non-indigenous species such as small encrusting forms may be limited to artifical structures (docks and marinas) and may be largely benign. Management measures employed to control the spread of invasive species, such as the application of aerial herbicides and pesticides, can pose hazards to nontarget species and further complicate management efforts. In the highly dynamic and disturbance-prone environment of the South Slough and the Coos estuary, future invasions by non-indigenous species may be amenable to control only by reduction of the mode and frequency of innoculations. Control of the invasive species problem within the Coos estuary and South Slough may require development and enforcement of international agreements on ballast water treatment, mid ocean exchange, and disposal as well as international and interstate regulations regarding the transport and release of mariculture products and other living materials into estuarine and coastal waters.

3.7 Emergent Salt Marshes

Emergent salt marshes occur in the South Slough as a distinct transitional ecotone at the interface between the estuarine and terrestrial ecosystems. Salt marshes are generally considered to serve several important ecological functions in the Pacific northwest including the contribution of primary marsh production into detritus food webs, seasonal accommodation of flood waters, improvement of estuarine water quality, and provision of resting and forage habitat for migratory birds.

Akins and Jefferson (1973) recognized eight different types of salt marshes within Oregon's estuaries. Descriptions of the physical and biotic characteristics of the different marsh types in the Pacific northwest region are provided by Seliskar and Gallagher (1983). Nearly all types of salt marshes occur within the South Slough estuary including: (a) Low sandy marshes (*i.e.,* Barview Wayside fringe marsh); (b) Low silty marshes (*i.e.,* Metcalf marsh island); (c) Sedge marshes (*i.e.,* Talbot Creek, John B., Fredrickson marshes); (d) Immature high marshes (*i.e.,* Kunz experimental marsh, cell #1); (e) Mature high marshes (*i.e.,* Hidden Creek, Stratigraphy Bay, Sloughside, Danger Point marshes); (f) Bulrush and sedge marshes (*i.e.,* Tom's Creek marsh); and (g) Diked salt marshes (*i.e.,* recovering marsh sites at Ferrie ranch, Kunz marsh, Dalton Creek, and Fredrickson north marsh). Local edaphic factors that affect the composition and distribution of emergent marsh communities include time and duration of tidal inundation, surface and soil pore water salinity, soil permeability and aeration, soil type, nutrient availability, extent of peat development, air and water temperature, drainage patterns, water table height, precipitation, and levels of incident light.

3.7.1 Geomorphology of South Slough Salt Marshes

Salt marshes occur throughout all regions of the South Slough estuary. Marsh geomorphology ranges from narrow fringing marshes located along the shoreline of the primary tidal channel, to protected pocket marshes connected by subsidiary tidal channels (located in the middle region of the South Slough), and to large deltaic marshes (>125 ac) in the low wet bottom lands in the riverine regions of the Winchester and Sengstacken arms of the estuary. Fringing marshes form on narrow elevated platforms that are drained by seeps and springs that originate in the adjacent mixed coniferous-deciduous forest. Pocket marshes typically contain a well-developed blind subsidiary tidal channel and a system of incised tertiary tidal creeks. In many cases the pocket marshes occur behind failed dikes and levees (*i.e.,* Ferrie marsh, Sloughside and Rhodes marshes, upper Elliott creek marsh) and the subsidiary tidal channel drains and fills through a breach in the earthen dike. Unmodified pocket marshes are rare and occur within the South Slough only at Hidden Creek and Stratigraphy Bay. Large sedge-dominated salt marshes occur in the deltaic bottom land of the Winchester Creek valley and within the Sengstacken arm of the estuary at the confluence of John B. and Talbot creeks. These sedge marshes provide conveyance for the principal sources of freshwater to the South Slough estuary. Island marshes located outside Metcalf marsh and on the south side of Valino Island constitute a fourth geomorphic type characterized by a flat open platform that is inundated on all sides by rising tides and surrounded on the perimeter by mudflats at low tide.

Ground truthing of USFWS – National Wetlands Inventory (NWI) designations was completed for 402 ha of estuarine and palustrine wetlands within the Charleston quadrangle (Graves, 1991; Figure 3.45). A total of 52 ha were incorrectly classified and another 16 ha were incorectly delineated. Collective evaluation of the individual wetland sites indicates that the NWI designation has an overall accuracy of about 83% within the rugged topographic relief of the South Slough watershed. The majority of erroneous wetland classifications were associated with misidentification of aquatic beds, incorrect interpretation of unconsolidated bottom sites that are subject to tidal fluctuations, and omission of narrow fringing marshes where the adjacent forest canopy interferes with interpretation of aerial photographs.

3.7.2 Emergent Salt Marsh Vegetation Communities

Salt marshes of the South Slough estuary are dominated by a species assemblage of 25-30 common emergent vascular plants (Table 3.16). The entire list of emergent marsh vegetation for South Slough includes about 45 species and is a representative subset of the 70 species described by Jefferson (1975) for Oregon salt marshes.

Several species are particularly common and characteristic of salt marshes thrououghout the South Slough estuary. Within the marine-dominated and mesohaline region 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*), Lyngbye sedge (*Carex lyngbyei*), sandspurry (*Spergularia marina*), spikerush (*Eleocharis parvula*), salt marsh bulrush (*Scirpus maritimus*) and seaside plantain (*Plantago maritima*). Parasitic dodder (*Cuscuta salina*) are also common in the low intertidal zone where they extend their tangle of orange filaments over pickleweed and

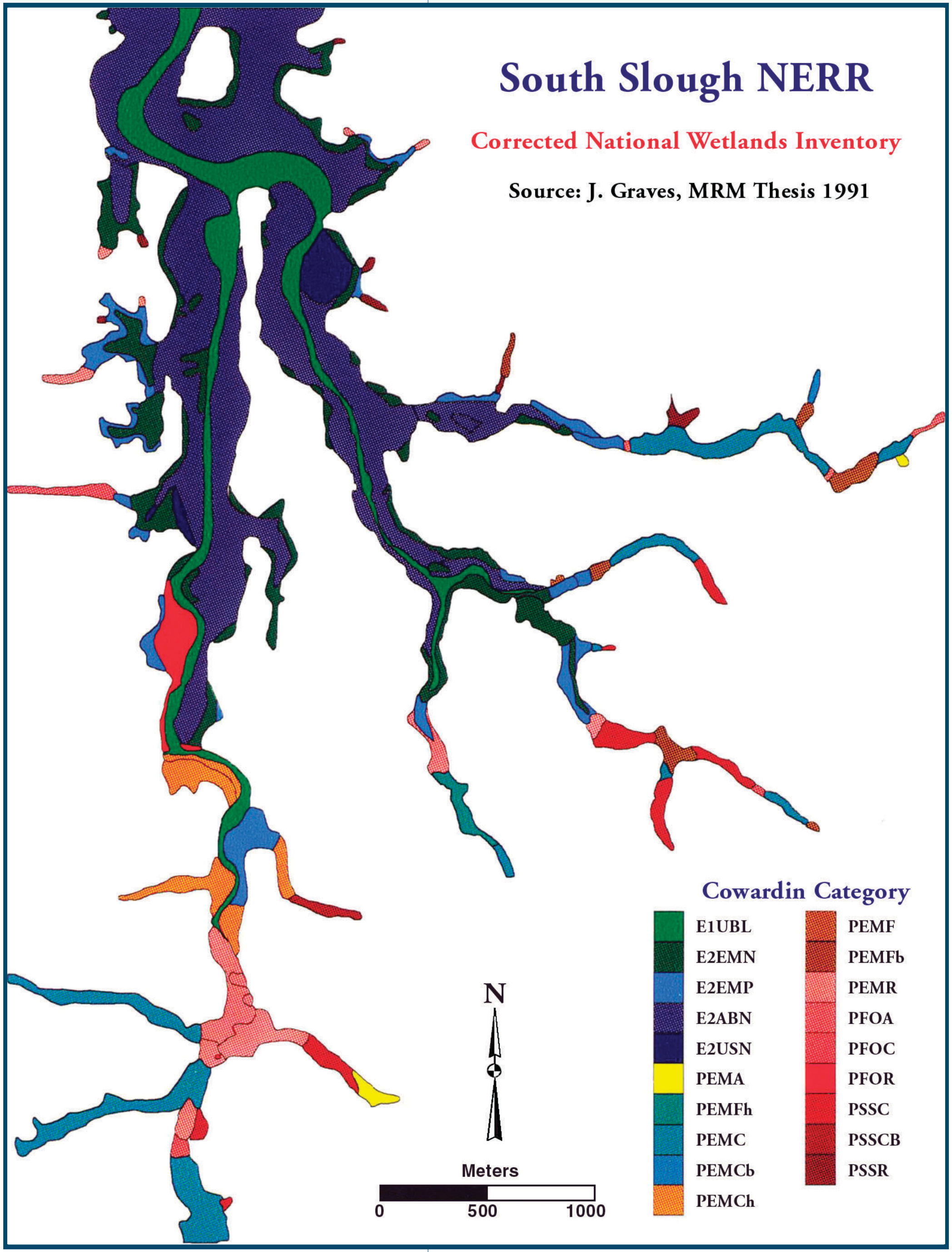


Figure 3.45. Corrected USFWS National Wetlands Inventory map for emergent marsh vegetation within the South Slough NERR, OR (adapted from Graves, 1991; see Cowardin *et al.*, 1979 for wetland delineation codes).

Table 3.16. Species list for emergent salt marsh vegetation within the South Slough NERR, OR. X indicates observation during transect surveys at Hidden Creek and Danger Point marshes. Zonation column indicates vertical distribution in the intertidal zone (H=High, L=Low, FW=freshwater; from Rumrill, 1991). FW species occur immediately outside the salt marsh.

Common name	Genus & species	Hidden Creek	Danger Point	Zonation
Yarrow	*Achillea* sp.	X		H
Creeping bentgrass	*Agrostis stolonifera*	X	X	H / L
Douglas aster	*Aster subspicatus*	X		H
Saltweed / Fat hen	*Atriplex patula*	X	X	H / L
Lyngbye's sedge	*Carex lyngbyei*	X	X	H / L
Slough sedge	*Carex obnupta*			H (FW)
Saltmarsh bird's-beak	*Cordylanthus maritimus palustris*			L
Brass buttons	*Cotula coronopifolia*	X		H / L
Smooth hawksbeard	*Crepis capillaris*			H
Dodder	*Cuscuta salina*	X	X	L
Tufted hairgrass	*Deschampsia caespitosa*	X	X	H / L
Saltgrass	*Distichlis spicata*	X	X	L
Creeping spikerush	*Eleocharis palustris*			L
Spikerush	*Eleocharis parvula*	X	X	H / L
Saltwort	*Glaux maritima*	X	X	L
Gumweed	*Grindellia integrifolia*	X	X	H
Cow parsnip	*Heracleum lanatum*			H
Velvet grass	*Holcus lanatus*			H
Meadow barley	*Hordeum brachyantherum*	X	X	H
Foxtail	*Hordeum jubatum*			H
Fleshy jaumea	*Jaumea carnosa*	X	X	L
Baltic rush	*Juncus balticus*	X	X	H
Marsh rush	*Juncus effusus pacificus*			H
Rush	*Juncus gerardii*		X	H
Lilaeopsis	*Lilaeopsis occidentalis*	X		L
Water parsley	*Oenanthe sarmentosa*			H
Paintbrush owl-clover	*Orthocarpus castillejoides*	X		L
Reed canarygrass	*Phalaris arundinaceae*			H
Seaside plantain	*Plantago maritima*	X		L
Pacific silverweed	*Potentilla pacifica*	X	X	H
Alkaligrass	*Puccinellia pumila*			L
Western dock	*Rumex occidentalis*			H
Ditch-grass	*Ruppia maritima*	X		L
Pickleweed	*Salicornia virginica*	X	X	L
American three-square	*Scirpus americanus*	X		L
Bulrush	*Scirpus cernuus*		X	H / L
Saltmarsh bulrush	*Scirpus maritimus*	X	X	L
Small-fruited bulrush	*Scirpus microcarpus*			H (FW)
Sandspurry	*Spergularia marina*	X	X	H / L
Springbank clover	*Trifolium wormskjoldii*	X		H
Arrowgrass	*Triglochin concinnum*			H / L
Seaside Arrowgrass	*Triglochin maritimum*	X	X	H / L
Cattail	*Typha latifolia*			L (FW)
Yellow-green mat	*Vaucheria*	X	X	L
Japanese eelgrass	*Zostera japonica*	X	X	L

derive moisture and nutrients from the host plant. Small isolated individuals of saltmarsh bird's-beak (*Cordylanthus maritimus palustris*) occur within the fringing marsh at Valino Island and also at the Ferrie Ranch marsh. Saltmarsh bird's-beak is federally recognized as a Category 2 Candidate Species (more information needed) and holds sensitive species status in Oregon as as a List 1 / TH species that is threatened throughout its range (Eastman, 1990).

Higher intertidal marsh communities are characterized by dense stands of tufted hairgrass (*Deschampsia caespitosa*), saltgrass, Lyngbye's sedge, and creeping bentgrass (*Agrostis stolonifera*), and also contain scattered patches of seaside arrowgrass, saltbush (*Atriplex patula*), gumweed (*Grindellia integrifolia*), and Pacific silverweed (*Potentilla pacifica*). At the highest intertidal elevations springbank clover (*Trifolium wormskjoldii*), Douglas aster (*Aster subspicatus*), yarrow (*Achillea* sp.) and velvetgrass (*Holcus lanatus*) mark the transition to the terrestrial upland community.

Composition of salt marsh communities differs substantially within the more riverine region of the estuary. Low intertidal marshes are exposed to greater freshwater influence and are typically characterized by dense and sometimes nearly monospecific stands of Lyngbye's sedge. Other species that commonly occur in the low sedge marshes include 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. Tall stands of the slough sedge (*Carex obnupta*) mark the transitional boundary to freshwater marshes and the uplands.

Tidal inundation is directly determined by intertidal elevation and serves as the primary factor that influences the distribution pattern of vegetation within any particular salt marsh.

Elevational ranges of individual species combine within the South Slough marshes to result in vertical stratification of the flora into high marsh and low marsh communities (Ewing and Seebacher, 1997; Figure 3.46). Emergent salt marsh vegetation typically occurs in the South Slough estuary within an elevational range of +1.15 to +2.35 m above NAVD. Some species have wide elevation ranges (*i.e., Carex, Triglochin, Salicornia, Deschampsia*). In other species the elevation range is relatively narrow (*i.e., Eleocharis, Spergularia*).

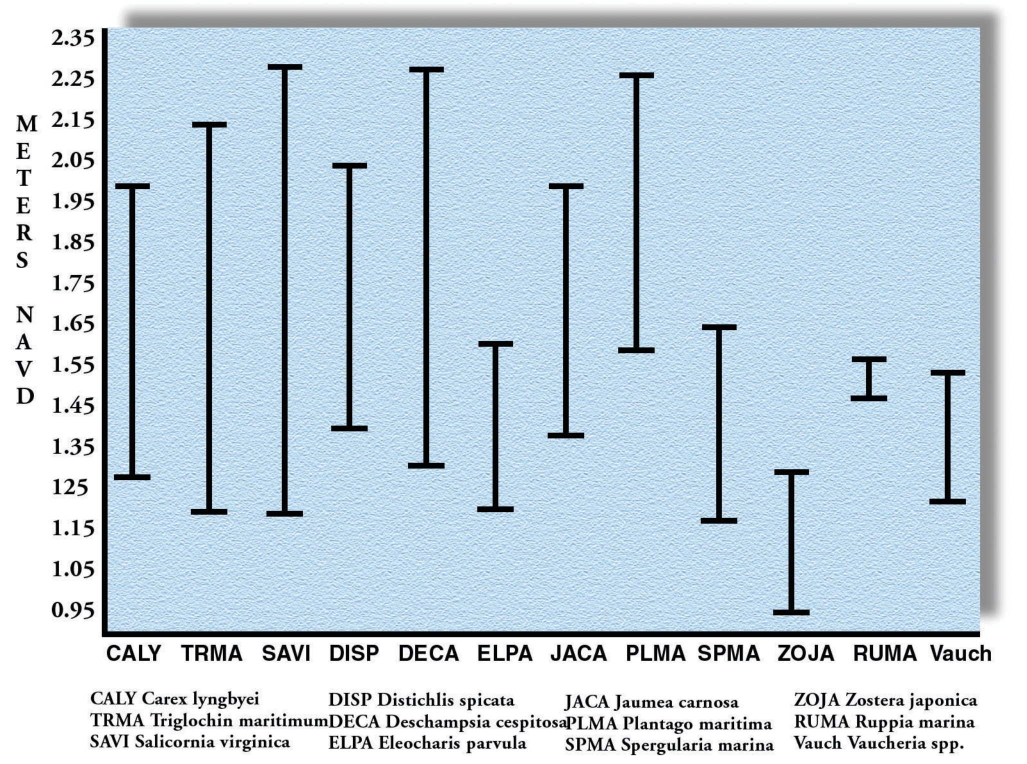


Figure 3.46. Distribution of common emergent salt marsh plants across an elevation gradient in the South Slough NERR, OR (from Ewing and Seebacher, 1997). NAVD is North American Vertical Datum.

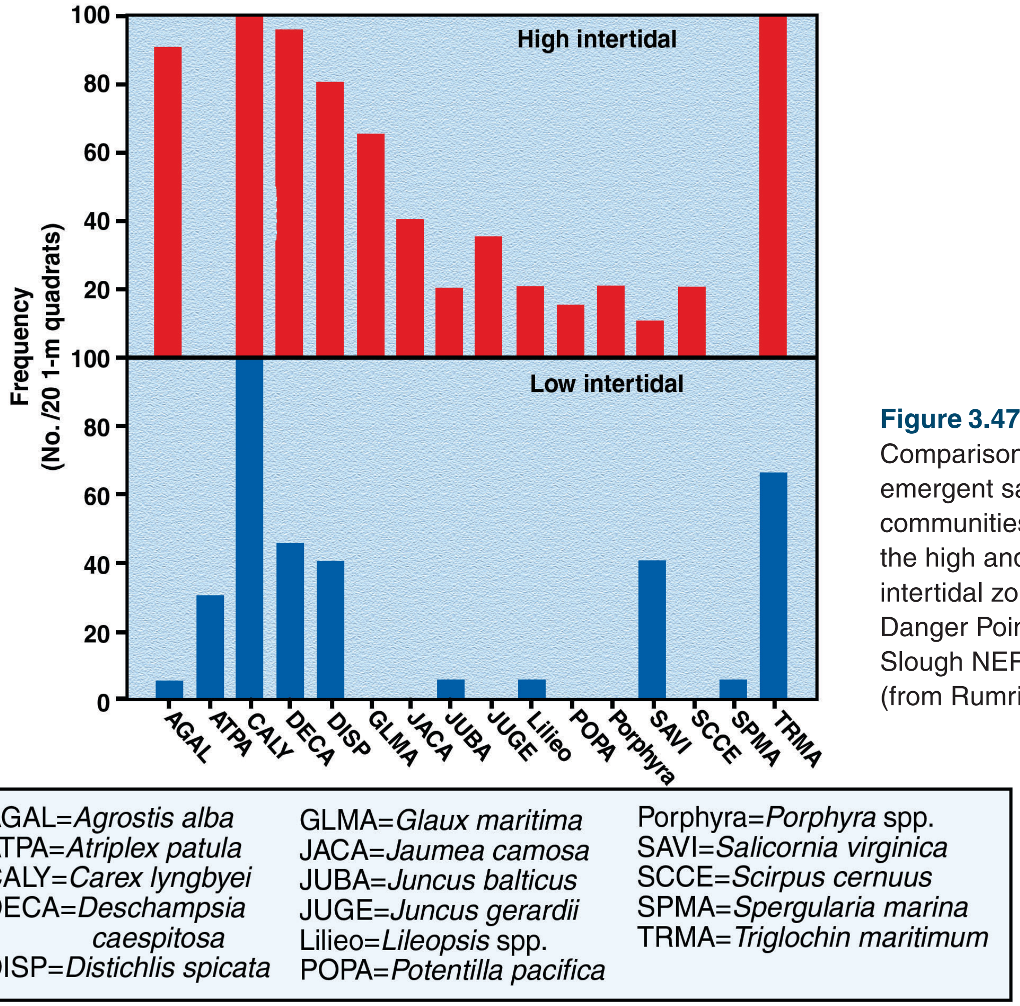


Figure 3.47. Comparison of emergent salt marsh communities between the high and low intertidal zones at Danger Point, South Slough NERR, OR (from Rumrill, 1991).

Although the high and low intertidal salt marsh communities are distinctly different, considerable overlap typically exists in the composition of species assemblages (see Table 3.16). For example, transect surveys conducted within the South Slough NERR (Danger Point marsh) illustrate that marsh communities exhibit greater diversity in the high intertidal zone (14 species) where 6 species were encountered at a frequency greater than 40% (5 species occurred in 80% or more of the quadrats; Figure 3.47). Conversely, marsh communities exhibit lower diversity in the low intertidal zone (10 species) where only 3 species were encountered at frequencies greater than 40%. Similarity between the high and low marsh assemblages was 50%, and 6 species occurred only in the high intertidal zone while 2 species were encountered only in the low zone. Reordering of the relative abundance of the 3 most frequently encountered species (*Carex, Triglochin, Deschampsia*) also adds considerable definition to the respective high and low marsh communities.

3.7.3 Salt Marsh Invertebrates

Invertebrate communities that inhabit the salt marshes of the South Slough estuary typically include oligochaetes, amphipods, isopods, snails, polychaetes, mites, and a variety of insects. Individuals of the introduced estuarine anemone (*Nematostella vectensis*) sometimes occur in shallow pools and wet mud within the salt marshes. Populations of *N. vectensis* are considered as rare and vulnerable to localized extinction in Great Britain and Ireland where they are afforded status as a protected species. Diversity and biomass of benthic invertebrates that inhabit the emergent salt marshes are low in comparison to adjacent tideflats and channels. Tissues from the salt marsh vegetation are generally inedible, and the invertebrates graze on microalgae that occur on the surface of the plants and the surface of the underlying marsh sediments. The invertebrate assemblages observed in the South Slough salt marshes are similar to those described by Hoffnagle *et al.*, (1976) who recorded cnidarians, nematodes, polychaetes, oligochaetes, araneae, acarina, barnacles, cumaceans,

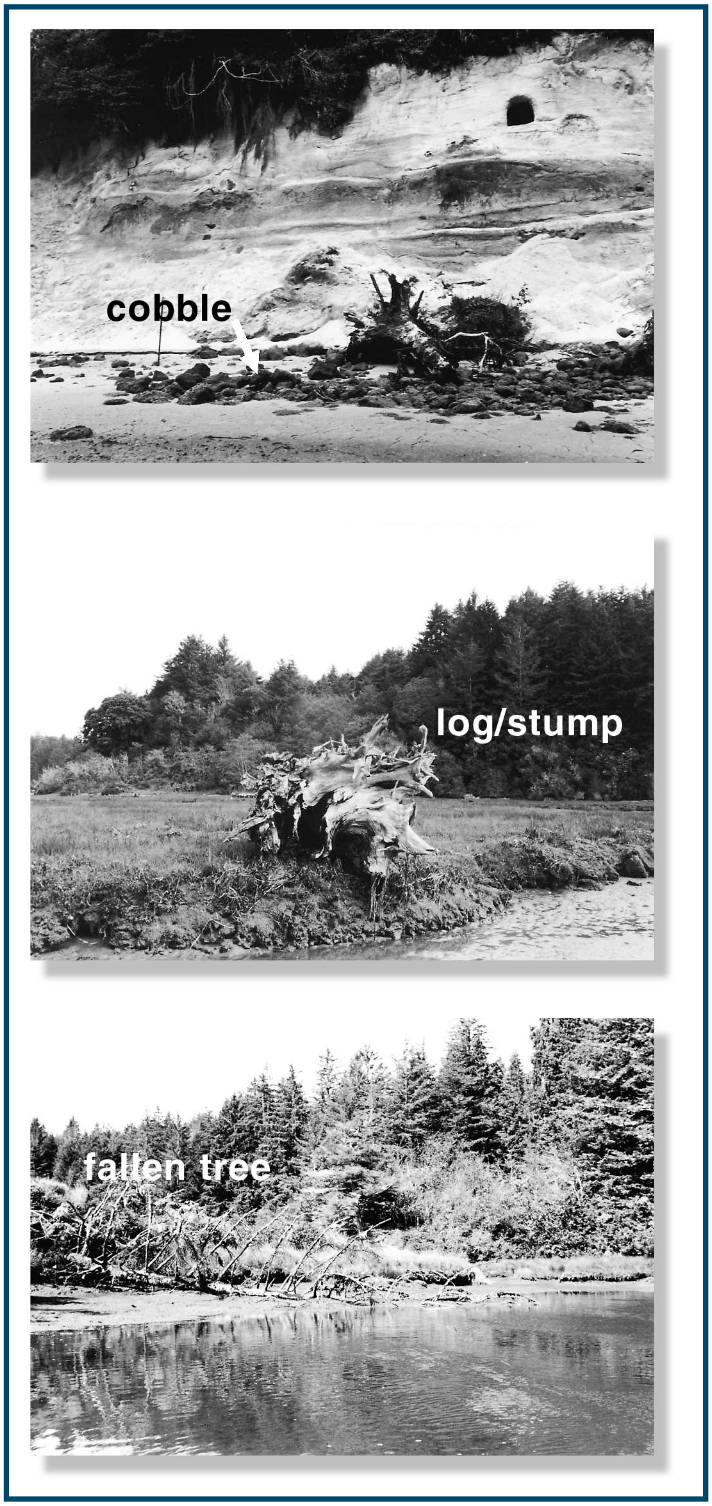


Figure 3.48. Naturally occurring hard substrata in the South Slough NERR, OR (adapted from Murray, 1993).

tanaids, isopods, amphipods, and many groups of insects (Diptera, Homoptera, Hemiptera, Hymenoptera, and others) in the intertidal salt marshes from South Slough and other regions of Coos Bay.

Benthic invertebrate communities that inhabit salt marshes in the riverine region of the South Slough are dominated by foraminifera, polychaetes (*Manayunkia aestuarina, Hobsonia florida, Capitella* spp.) oligochaetes, and amphipods. Chironomid larvae and pupae were found in high numbers in open patches of bare substrata, while Ceratopogonid larvae and pupae are abundant among the emergent vegetation (Fritz, 2001). Gastropods (*Assiminea californica, Littorina subrotundata, Ovatella myosotis*), isopods (*Gnorimosphaeroma insulare*), and amphipods (*Corophium salmonis, Eogammarus confervicolus*) are locally abundant within some salt marsh sites. Insects probably utilize more of the marsh plant production than do the benthic grazing invertebrates, but only a small portion of the marsh vegetation is directly consumed.

The snail (*Ovatella myosotis*) is a non-indigenous species that has recently become established in the high intertidal salt marshes of the South Slough estuary (Carlton, 1989). Berman (1989) conducted manipulative experiments to determine whether the distribution or abundance of native gastropods (*Assiminea californica, Littorina subrotundata*) were affected by presence of the introduced snail. These three species exhibit a strong vertical zonation pattern where *O. myosotis* is abundant in the high zone and *A. californica* and *L. subrotundata* are more abundant in the low intertidal marsh. All three snails graze on microalgal mats of diatoms and other plants. Results from transplant and removal experiments did not provide evidence of direct competitive interactions among the species, and indicate that success of *O. myosotis* is determined by utilization of spatial and trophic resources that are not exploited by the native species.

3.7.4 Ecological Importance of Salt Marshes

Salt marsh habitats in the northern region of the South Slough estuary have been altered significantly over the past century by human activities including dredging of the Charleston navigational channel, construction of the Charleston Boat basin, and the filling of salt marshes for industrial and municipal development. In the middle and southern region, salt marshes have been altered or lost due to dredging to facilitate transport of floating log rafts, as well as by diking and draining primarily for agricultural purposes. These alterations to the emergent salt marsh habitats have resulted in changes to the dynamics of estuarine food webs and tidal circulation patterns, which may in turn influence the residence times and migratory behavior of salmon smolts and returning adults. Several significant issues remain to be clarified, however, regarding the role to which habitat alterations within estuaries such as the South Slough contribute to the widespread decline in populations of Pacific salmon. It is likely that obstacles to the recovery of salmon populations reflect the combination of adverse conditions in the Pacific Ocean, continued fishing and predation, alteration of processes within estuaries, and damage to spawning habitat and migratory corridors within natal freshwater streams and coastal watersheds.

3.8 Hard Substrata and Anthropogenic Habitats

The South Slough estuary is inhabited by a diverse community of nearly 80 species of encrusting invertebrates that are attached to hard substrata and anthropogenic structures (Table 3.17). Of these encrusting or epifouling organisms, about 85% are native species, 10% are non-indigenous, and 5% are cyrptogenic (Hewitt, 1993).

With the exception of docks and marinas, the spatial extent of hard surfaces that are suitable substrata for epifouling communities is very limited in the South Slough estuary (Figure 3.48). Naturally-occuring hard substrata include two small cliffs of exposed bedrock, minor beds of gravel and cobble, and an extensive scattering of miscellaneous woody material comprised primarily of downed trees, logs, branches, and stumps (Murray, 1993). A steep cliff of exposed sedimentary bedrock at Collver Point (in the northern region of the estuary) is inhabited by rock weeds (*Fucus*), mussels (*Mytilus* spp.), limpets (*Lottia* spp.), barnacles (*Balanus glandula, Semibalanus cariosus*), periwinkles (*Littorina* sp.), and boring clams (*Adula californiensis, Penitella penita, Zirfaea pilsbryi*). A second small escarpment of low (*ca.* 2 m) overhung sandstone cliffs occurs immediately north of Elliott Creek in the mesohaline region of the Sengstacken arm. Gravel and cobble located

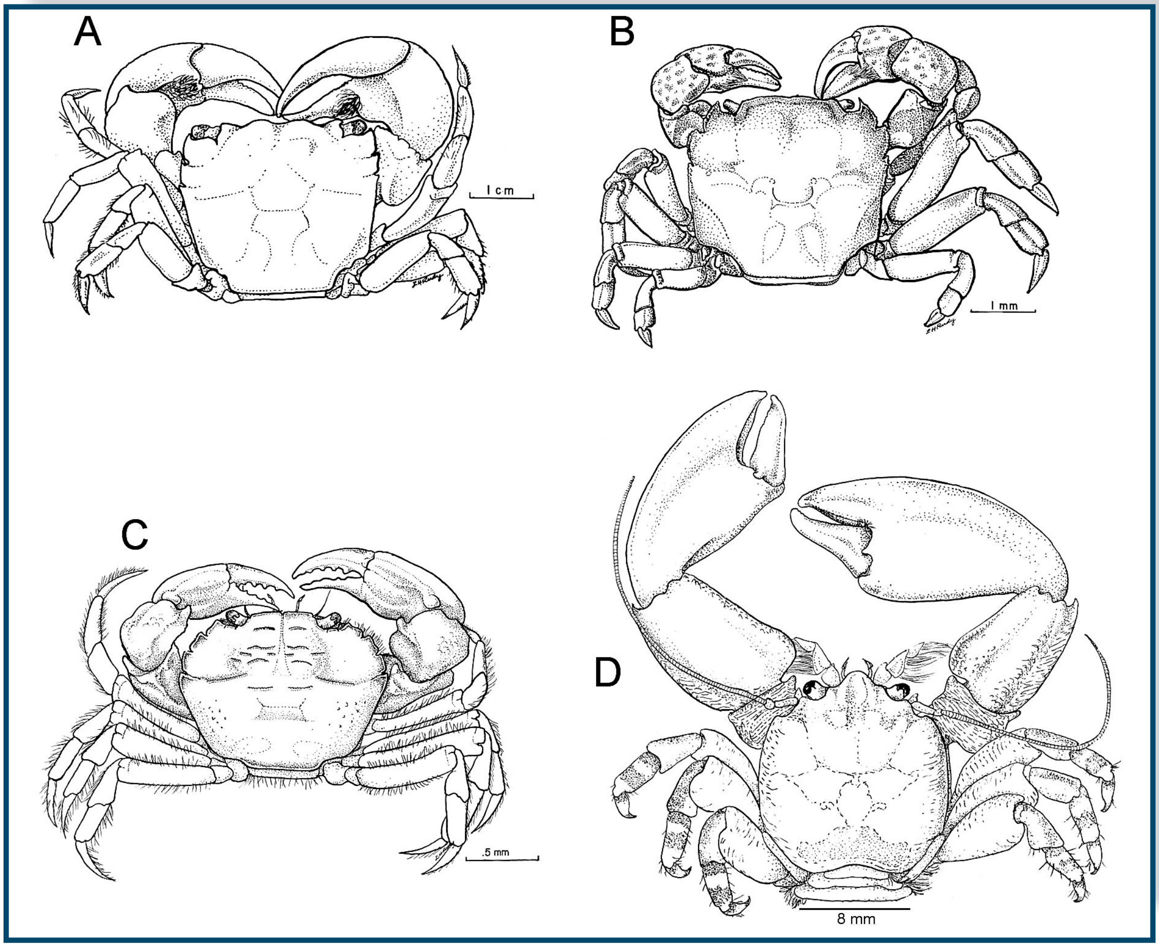


Figure 3.49. Representative decapod crustaceans that inhabit rocky habitats within the South Slough NERR, OR. A) *Hemigrapsus oregonensis*; B) *Hemigrapsus nudus*; C) *Rhithropanopeus harrisii*; D) *Petrolisthes cinctipes* (adapted from Rudy and Rudy, 1983).

Table 3.17. Species list of encrusting or epifouling invertebrates in South Slough (adapted from Hewitt, 1993).

TAXON	ORIGIN N= NATIVE I=INTRODUCED/ CRYPTOGENIC	Location within South Slough: PT. ADAMS JETTY (ROCK)	CHARLESTON BOAT BASIN (FLOATS, PILINGS)	HALLMARK FISHERIES DOCK (FLOATS, PILINGS)	DEEP WATER FLEET FACILITY (FLOATS, PILINGS)	SOUTH SLOUGH (OYSTER SHELLS, LOGS)
P. Cirripedia						
Balanus improvisus	I		X			X
Balanus crenatus	N	X	X	X		X
Balanus glandula	N	X	X	X	X	X
Balanus nubilus	N	X	X	X		X
P. Cnidaria						
Aglaophenia spp.	N	X				
Anthopleura xanthogrammica	N	X				
Epiactis prolifera	N	X				
Hydroid (*Phialella?*)	N	X	X			X
Metridium senile	N	X	X			X
Obelia spp.	N	X	X		X	X
Sarsia spp.	N	X				
Scyphistomae (*Aurelia* sp?)	N	X	X			
Tubularia indivisa	N	X				
Tubularia marina	N	X	X			
Urticina crassicornis	N	X	X			
Zanclea sp.	N	X				
P. Ectoprocta						
Alcyonidium poluoum	N	X		X	X	
Bowerbankia gracilis	I	X	X	X		X
Bugula neritina	I		X			
Bugula pacifica	N	X	X			X
Callopora circumclathra	N	X				
Callopora horrida	N	X				
Caulibugula ciliata	N	X	X			
Cheilopora praelonga	N	X				
Coleopora gigantea	N	X				
Conopeum tenuissimum	I	X	X			X
Costazia costazii	N	X				
Cribrilina annulata	N	X	X			
Crisia occidentalis	N	X				
Cryptosula pallasiana	I	X	X	X	X	
Dendrobeania lichenoides	N	X				
Electra crustulenta	N	X				
Electra crustulenta arctica	N	X				
Fenestrulina malusii umbonata	N	X				
Filicrisia franciscana	N	X				
Hippothoa hyalina	N	X	X	X	X	X
Microporella californica	N	X	X			
Microporella ciliata	N	X	X			
Oncousoecia ovoidea	N	X				
Parasmittina trispinosa	N	X				

Table 3.17 Continued next page

Table 3.17 Continued

TAXON	ORIGIN N= NATIVE I=INTRODUCED/ CRYPTOGENIC	Location within South Slough: PT. ADAMS JETTY (ROCK)	CHARLESTON BOAT BASIN (FLOATS, PILINGS)	HALLMARK FISHERIES DOCK (FLOATS, PILINGS)	DEEP WATER FLEET FACILITY (FLOATS, PILINGS)	SOUTH SLOUGH (OYSTER SHELLS, LOGS)
Porella columbiana	N	X				
Rhamphostomella costata	N	X	X			
Schizoporella unicornis	I	X	X	X	X	X
P. Ectoprocta con't.						
Smittoidea prolifica	N	X	X			X
Tricellaria erecta	N	X				
Tricellaria sp.	N	X				
Watersipora edmonsonii?	I		X		X	
P. Entoprocta						
Loxosoma spp.	N	X				
Pedicellina cernua	N	X				
P. Mollusca						
Crassostrea gigas	I	X	X	X	X	X
Hinnites gigantea	N	X	X			
Mytilus californianus	N	X				
Mytilus trossulus	N	X	X	X	X	X
Pododesmus cepio	N	X	X		X	
P. Porifera						
"Ophlitaspongia" spp.	N	X		X		
Halichondrea bowerbanki	I	X	X			X
Halichondria panicea	N	X				
Haliclona sp.	N	X	X			
Haliclona sp.	I					X
Leucosolenia sp.	N	X	X			
Myxilla sp.	N	X		X		
P. Annelida						
Crucigera zygophora	N	X	X		X	
Eudistylia polymorpha	N	X				
Eudistylia vancouveri	N	X	X	X		X
Pseudochitinopoma occidentali	N	X				
Serpula vermicularis	N	X	X		X	X
Spirorbids	N	X	X	X		
Terebellid spp.	N	X	X			
P. Urochordata						
Ascidia ceratodes	N	X				
Boltenia echinata	N	X				
Botrylloides violaceus	I	X	X		X	X
Botryllus schlosseri	I	X	X		X	X
Cnemidocarpa finmarkiensis	N	X				
Distaplia occidentalis	N	X	X	X	X	
Molgula manhattensis	I		X			
Perphora annectens	N	X				
Pyura haustor	N	X	X			
Styela gibbsi	N	X	X			
Styela montereyensis	N	X	X			
SPECIES RICHNESS						
NATIVE		66	31	11	9	12
INTRODUCED		8	11	4	6	8

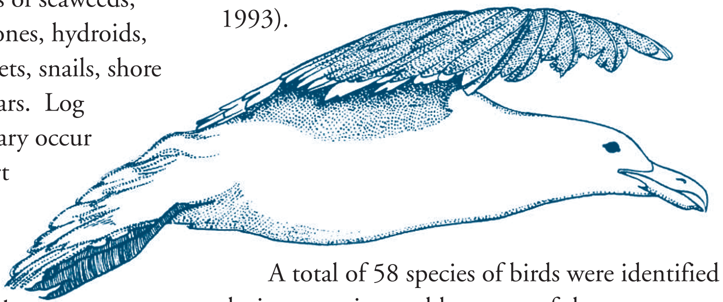
sporadically throughout the estuary provide sheltered habitat for shore crabs (*Hemigrapsus nudus, H. oregonensis*) and porcelain crabs (*Petrolisthes eriomerus*; Figure 3.49) as well as rock weed and other brown algae (*Pilayella* sp.), green algae (*Ulva* spp., *Enteromorpha* spp.), red algae (*Polysiphonia*), and periwinkles. The fallen trees, branches, stumps, and other miscellaneous hard substrata are typically inhabited by surface films of diatoms, green algae, rockweed, and a variety of epifouling organisms including barnacles (*B. glandula, B. improvisus, S. cariosus*), mussels, periwinkles, limpets (*Lottia* spp., *Onchidella borealis*), and anemones (*Haliplanella luciae*). Several species of motile invertebrates also live on the fallen wood structures including insects, mites, isopods, amphipods, shore crabs, and rare individuals of the dorid nudibranch (*Archidoris montereyensis*).

A variety of hardened anthropogenic structures or constructed habitats occur within the South Slough estuary and provide artifical substratum for diverse communities of epifouling organisms. These anthropogenic structures include imported rip-rap rock boulders used to construct the Point Adams jetty at the mouth of the South Slough, and a series of floating docks, marinas, industrial piers, and their associated wood and concrete pilings (located along the shoreline of the South Slough in Charleston). In addition, several large concrete stanchions rise out of the estuary to support the Charleston Bridge. Hewitt (1993) recorded 74 species of encrusting or epifouling invertebrates from the Point Adams jetty, 15 encrusting species from the floating docks and an industrial pier in the outer boat basin exposed to the primary tidal channel, and over 40 species from floating docks in the protected inner boat basin (Table 3.17). The rock, concrete and wood substrata are inhabited by diverse communities of seaweeds, sponges, tunicates, bryozoans, anemones, hydroids, polychaetes, barnacles, mussels, limpets, snails, shore crabs, isopods, amphipods, and seastars. Log pilings scattered throughout the estuary occur as historical remnants of log transport operations. Like their natural wooden counterparts, the old log pilings support communities of diatoms, green algae, barnacles, mussels, and occasional snails and limpets. Northwest shipworms (*Bankia setacea*) and gribbles (*Limnoria tripunctata*) bore into the decayed log pilings and submerged wood.

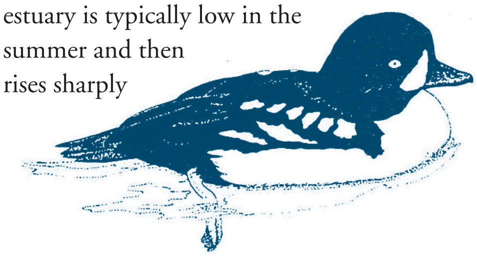
Commercial plots of the Pacific oyster (*Crassostrea gigas*) constitute a special type of anthropogenic reef or biotic hardened substrata within the littoral zone of the South Slough estuary. Physical structure of the oyster reefs varies from ground culture plots (where cultch shells and living oysters are placed directly on the muddy substratum) to dense arrays of stakes (with clumps of attached oysters raised about 0.5 m off the bottom; Figure 3.50). These commercial oyster reefs typically occur as isolated and angular patches of complex three-dimensional hard substrata surrounded by expansive soft sediment mudflats and eelgrass beds. Hewitt (1993) recorded 20 species of encrusting or epifouling invertebrate species from oyster shells and logs at Valino Island (Table 3.17). Particularly diverse communities of epifouling organisms develop within the matrix of oyster shells including green, red, and brown algae, sponges, tunicates, encrusting bryozoans, crabs, shrimp, barnacles, mussels, tunicates, hydroids, amphipods, polychaetes, snails, nudibranchs, limpets, and sometimes seastars.

3.9 Migratory Birds and Waterfowl

Open tidal channels, intertidal flats, and salt marshes of the South Slough estuary provide important resting and forage areas for a wide variety of migratory and resident shorebirds and waterfowl. Annual aerial waterfowl surveys conducted during winter months by the US Fish and Wildlife Service recorded over 4,000 waterfowl in the entire Coos estuary, and over 2,000 of the individuals occurred in the South Slough. In addition, over 7,000 individual shorebirds have been observed along the shoreline of the Coos estuary (with over 2,000 of these present in South Slough) during mid winter surveys conducted by the Cape Arago Audubon Society (Lance *et al.,* 1993).



A total of 58 species of birds were identified during a semi-monthly census of the open water habitats and shoreline of the South Slough estuary (Lance *et al.,* 1993). A substantial subset of these were observed in flight the at mouth of the estuary, including 16 species of waterfowl, 5 species of gulls, 3 species of shorebirds, and a variety of herons, loons, terns, cormorants, and other species (Table 3.18). Western gulls (*Larus occidentalis*), Dunlin (*Calidris alpina*), sanderlings (*C. alba*), double-crested cormorants (*Phalacrocorax auritus*), greater scaup (*Aythya marila*), buffleheads (*Bucephala albeola*), common goldeneye (*Bucephala clanga*), American wideon (*Anas americana*), and gadwall (*A. strepera*) are among the most numerous birds observed in the open water and shoreline habitats of the South Slough estuary. The number of birds observed in the estuary is typically low in the summer and then rises sharply in November to remain high through winter until March (Figure 3.51). Peak numbers of birds occur in December when combined waterfowl numbers ranged between 2,100 and 3,300 individuals and all other birds total 2,000 to 4,000 individuals. Birds observed entering or exiting the mouth of the South Slough estuary followed a strong daily bimodal activity pattern with peak migrations in and out of the estuary at dawn and dusk (Figure 3.52). The ecological impacts of foraging shorebirds and waterfowl on populations of infaunal invertebrates has not been investigated within the South Slough estuary.



3.10 Use of Estuarine Habitats by Mammals

Several species of opportunistic, estuarine-dependent, and aquatic mammals forage, rest and sometimes reside in Pacific northwest estuaries (Magwire, 1976; Simenstad, 1983). These include deer mice (*Peromyscus maniculatus*), vagrant shrew (*Sorex vagrans*), raccoon (*Procyon lotor*), Columbian black-tailed deer (*Odocoileus hemionus columbianus*), American beaver (*Castor canadensis*), muskrat (*Ondatra zibethica*), nutria (*Myocastor coypus*), river otter (*Lutra canadensis*), harbor seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), northern sea lions (*Eumetopias jubata*), and occasional juveniles of the northern elephant seal (*Mirounga angustirostris*). Rats, mice, shrews, raccoons, beavers, muskrat, and nutria are often found in direct association with salt marshes (Magwire, 1976), while

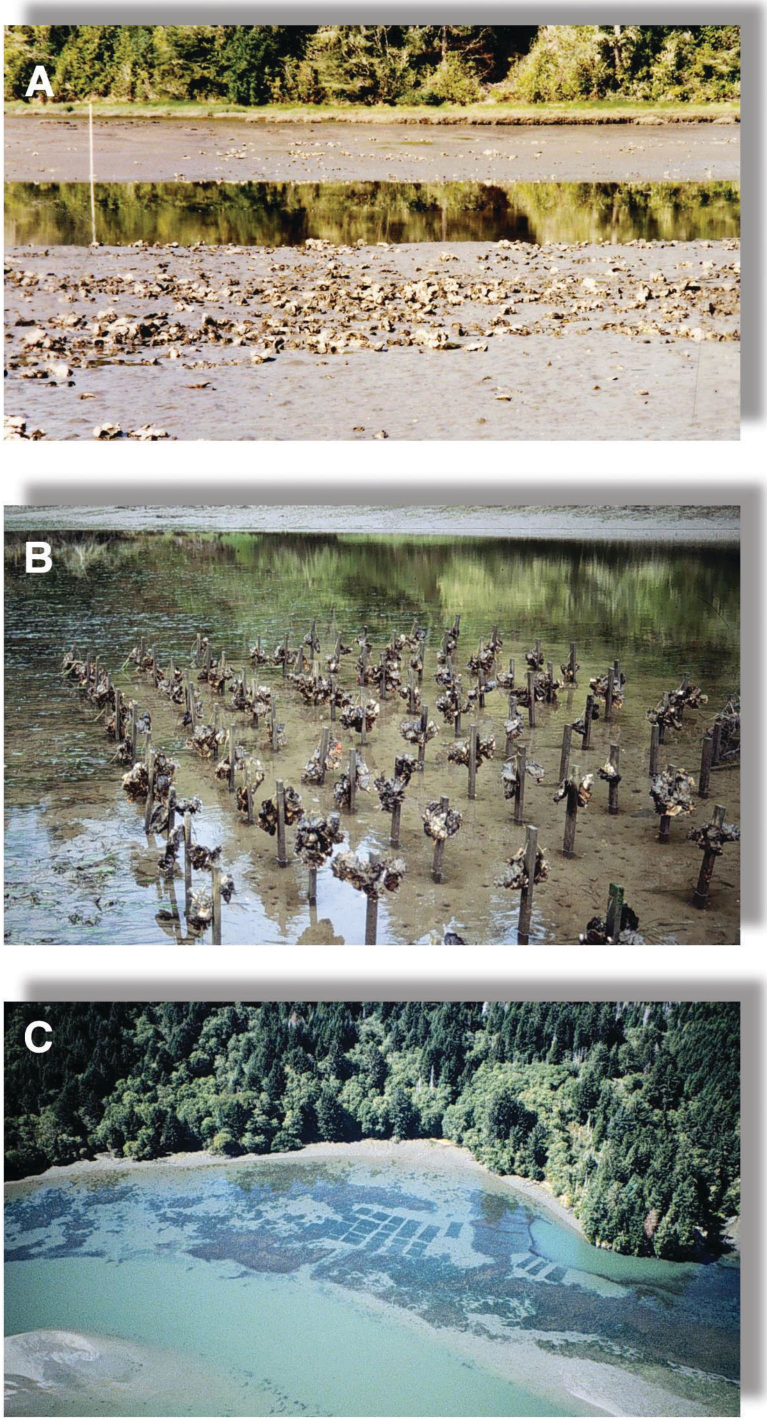


Figure 3.50. Commercial mariculture of the Pacific oyster (*Crassostrea gigas*) within the South Slough NERR, OR. A) Ground culture; B) Stake culture; C) Aerial photograph of stake culture plots.

Table 3.18. Species list of birds observed crossing the Pacific Power lines at the Charleston Bridge, mouth of the South Slough estuary (September 1992-March 1993; adapted from Lance *et al.*, 1993).

Family	*Genus species*	Common name	Type
Gaviidae:	*Gavia immer*	Common loon	Loon
	Gavia pacifica	Pacific loon	Loon
Podicipedidae:	*Aechmophorus occidentalis*	Western grebe	Grebe
Pelecanidae:	*Pelicanus occidentalis*	Brown pelican	Pelican
Phalacrocoracidae:	*Phalacrocorax auritus*	Double-crested cormorant	Cormorant
	Phalacrocorax pelagicus	Pelagic cormorant	Cormorant
Ardeidae:	*Ardea herodias*	Great blue heron	Heron
	Casmerodius albus	Great egret	Heron
Anatidae:	*Anas acuta*	Northern pintail	Waterfowl
	Anas americana	American wigeon	Waterfowl
	Anas crecca	Green-winged teal	Waterfowl
	Anas platyrhynchos	Mallard	Waterfowl
	Anas strepera	Gadwall	Waterfowl
	Aythya affinis	Lesser scaup	Waterfowl
	Aythya marila	Greater scaup	Waterfowl
	Aythya valisineria	Canvasback	Waterfowl
	Bucephala albeola	Bufflehead	Waterfowl
	Bucephala clangula	Common goldeneye	Waterfowl
	Melanitta fusca	White-winged scoter	Waterfowl
	Melanitta nigra	Black scoter	Waterfowl
	Melanitta perspicillata	Surf scoter	Waterfowl
	Mergus merganser	Common merganser	Waterfowl
	Mergus serrator	Red-breasted merganser	Waterfowl
	Oxyura jamaicensis	Ruddy duck	Waterfowl
Scolopacidae:	*Calidris alba*	Sanderling	Shorebird
	Calidris alpina	Dunlin	Shorebird
		Unidentified shorebird	Shorebird
Laridae:	*Larus canus*	Mew gull	Gull
	Larus delawarensis	Ring-billed gull	Gull
	Larus heermanni	Heerman's gull	Gull
	Larus occidentalis	Western gull	Gull
	Rissa tridactyla	Black-legged kittiwake	Gull
	Sterna elegans	Elegant tern	Tern
	Sterna caspia	Caspian tern	Tern
Accipitridae:	*Haliaeetus leucocephalus*	Bald eagle	Eagle

the river otters, seals, and sea lions are usually observed either in primary tidal channels or on the littoral flats adjacent to deep channels (Thom, 1987).

Harbor seals (*Phoca vitulina*) are frequently observed in the South Slough estuary during their haul-outs on exposed sandflats across the channel from Collver Point. Groups of 35-60 adult and juvenile harbor seals typically rest during low tide on the sandy bank of the tidal channel, and they sometimes occur in groups of over 100 individuals. The numbers of *P. vitulina* are usually greatest in winter and spring and coincide with the availablity of forage fish. A few harbor seals haul-out infrequently on the sandy beach at the base of Younker Point. Individuals of *P. vitulina* have been observed to explore up the Winchester arm of the South Slough as far as Lattin Dike (6.5 km from the mouth of the estuary) and up the Sengstacken arm as far as

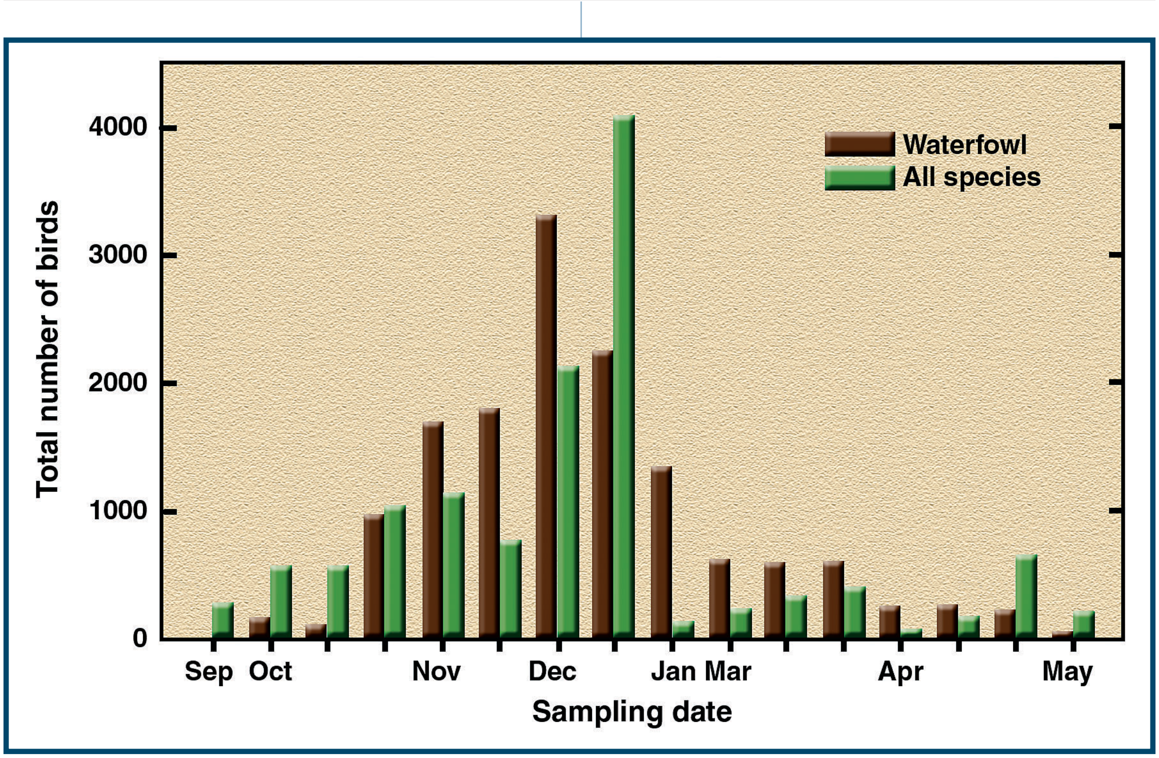


Fig. 3.51. Seasonal observations of the total number of birds in the South Slough estuary (September 1992-March 1993; adapted from Lance *et al.*, 1993).

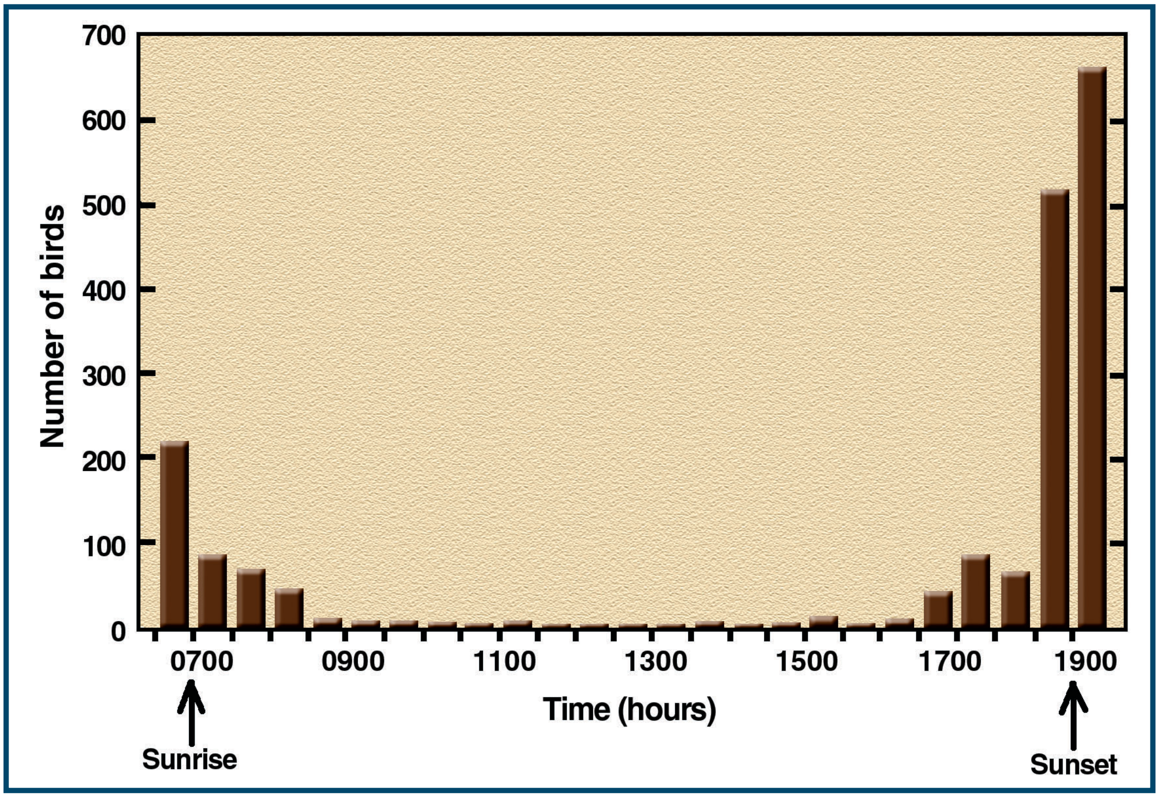
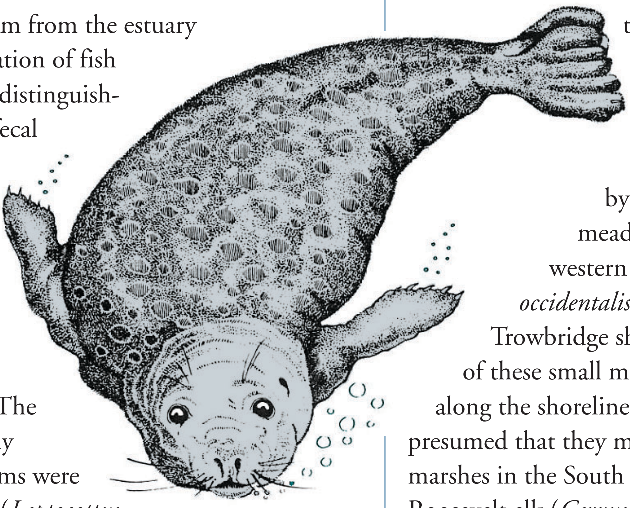


Fig. 3.52. Daily bimodal activity pattern for birds observed entering or exiting the mouth of the South Slough estuary (adapted from Lance *et al.*, 1993).



Elliot Creek (5.5 km from the estuary mouth). Identification of fish otoliths and other distinguishing remains from fecal material indicated that harbor seals that foraged in South Slough and Coos Bay had a catholic diet of over 20 prey items (Graybill, 1981). The five most frequently consumed prey items were staghorn sculpins (*Leptocottus armatus*; 87% frequency in scat), English sole (*Pleuronectes vetulus*; 67%), shiner perch (*Cymatogaster aggregata*; 59%), Pacific herring (*Clupea pallasi*; 57%), and cephalopod beaks (45%).

Raccoon and river otter are also commonly observed in the South Slough. Raccoons (*Procyon lotor*) typically forage nocturnally and during early morning low tides in the exposed mudflats throughout the estuary where they prey upon clams, crabs, mussels, barnacles, and other invertebrates. Raccoon paw prints are nearly ubiquitous in the soft intertidal mudflats and provide evidence of their frequent low tide foraging activity. River otters (*Lutra canadensis*) are also frequently observed in riverine regions of Winchester Creek and Talbot Creek tidal channels. Likely prey items for river otters in the South Slough include shrimp (*Crangon franciscorum*), bivalves, (*Mya arenaria*), and small fish (*Leptocottus armatus, Cymatogaster aggregata*). River otters are occasionally seen in the mesohaline and marine-dominated regions of the estuary, although they are frequently sighted in the Charleston boat basin where they use floating docks as sites to rest and feed on prey items captured within the marina.

Magwire (1976) conducted a survey of small mammal populations within the salt marshes of Coos Bay. Six species of small mammals were captured in the low, mid, and high intertidal salt marshes including vagrant shrews (71% of captures) and deer mice (23% of captures), with the remainder contributed by small numbers of Oregon meadow mice (*Microtus oregonii*), western red-backed mice (*Clethrionomys occidentalis*), black rats (*Rattus rattus*), and Trowbridge shrews (*Sorex trowbridgii*). Most of these small mammals have been observed along the shoreline of the South Slough, and it is presumed that they make similar use of the salt marshes in the South Slough estuary. Small herds of Roosevelt elk (*Cervus elaphus roosevelti*) often forage and rest in the freshwater marshes, and they are sometimes observed crossing the fringing salt marshes.

American beaver (*Castor canadensis*) feed on the bark from deciduous red alder trees (*Alnus rubra*) that grow prolifically along the shoreline of the South Slough, and they construct rudimentary dams of fallen trees, branches, sticks, and vegetation at many locations. Beaver ponds are usually constructed in the subsidiary tidal creeks and freshwater wetlands immediately upstream from the head of tide. The beaver ponds impound significant volumes of water, flood the emergent vegetation of the low valley bottom lands, and provide lacustrine habitat for diverse communities of aquatic insects, rough-skinned newts (*Taricha granulosa*), red-legged frogs (*Rana aurora aurora*), fish (three-spine stickleback, *Gasterosteus aculeatus*; cutthroat trout, O*nchorhynchus clarki clarki*; coho salmon, *O. kisutch*; Pacific lamprey, *Lampetra tridentatus*), and several species of waterfowl.

Chapter 4

Riparian Communities and Upland Habitats

by: C. Sheridan and S. Rumrill

4.1 Riparian Habitats and Upland Forests in the Oregon Coast Range

Riparian habitats and upland forests within the South Slough watershed exhibit structural elements and compositional features that are characteristic of a temperate coastal forest in the southern region of the Oregon Coast Range. The multi-storied upland forest is typically dominated in climax condition by western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), and the earlier seral stages contain a diverse assemblage of associate conifers including Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and Port-Orford-cedar (*Chamaecyparis lawsoniana*). Deciduous trees (particularly red alder: *Alnus rubra*) are abundant along streambanks in riparian habitats, and they form densely-shaded overstory canopies in forested wetlands. Lush understory vegetation composed of shrubs and ferns also thrive in the deep moist soils, and the forest floor is typically inhabited by a rich assemblage of mosses, lichen, fungi, and liverworts. The wet Pacific maritime climate delivers abundant rainfall to the coastal watersheds, and the forest stands and riparian habitats are protected from drying by frequent fog, mist, and cloud cover.

4.2 Riparian Habitats and Communities in the South Slough Coastal Watershed

The South Slough watershed contains about 6,935 ha of riparian habitats and upland forests (Figure 4.1). Numerous dendritic streams drain the regions above the head of tide and convey water into the Winchester and Sengstacken arms of the South Slough estuary. Hydrogeomorphic processes within the network of streams continuously reshape the drainage system and have an important influence on the composition and structure of riparian habitats and communities (Naiman, *et al.*, 1992; 2000).

4.2.1 Distribution and Extent of Riparian Habitats

Several watershed sub-basins located within the South Slough NERR contribute to Winchester Creek (a 5th order stream) and the Winchester Creek arm of the estuary. These include (in descending order of size) Cox Canyon Creek, Wasson Creek, Anderson Creek, Dalton Creek, Hidden Creek and Tom's Creek (see Figures 2.14 and 4.1). The eastern Sengstacken arm of the estuary is fed by several 4th order streams and sub-basins including (in descending order) Elliott Creek, John B. Creek, and Talbot Creek. Three significant watershed sub-basins (Day Creek, Bronx Creek, and the Hayward Creek system) drain directly into South Slough north of the junction between the Winchester and Sengstacken arms. Winchester Creek and the Sengstacken arm of the South Slough are generally oriented along the north-south axis. In contrast, most 2nd and 3rd order streams that drain into these systems are oriented along the east-west axis which lends inherent protection from the dominant northernly and southernly windstorms. Many smaller intermittent creeks and spring systems contribute to the Winchester Creek watershed south and north of the administrative boundaries of the South Slough NERR.

The 12 significant watershed sub-basins described above encompass 1,086 ha or 56% of the total spatial extent of the South Slough NERR. These sub-basins encompass a spatial mosaic of riparian habitats and upland forest types. The riparian areas function as transitional ecotones between adjacent terrestrial upland systems and aquatic freshwater and estuarine systems (Gregory *et al.*, 1991). Riparian habitat areas extend along the lowlands and creek bottoms, and they are generally linear in shape with spatial measurements that are far lower than that of the surrounding uplands. Denike *et al.*, (1992) surveyed eight riparian systems within the South Slough NERR that encompass about 83 ha or 4.3% of the total Reserve area (Figure 4.1). Stone (1987) described the geomorphology and condition

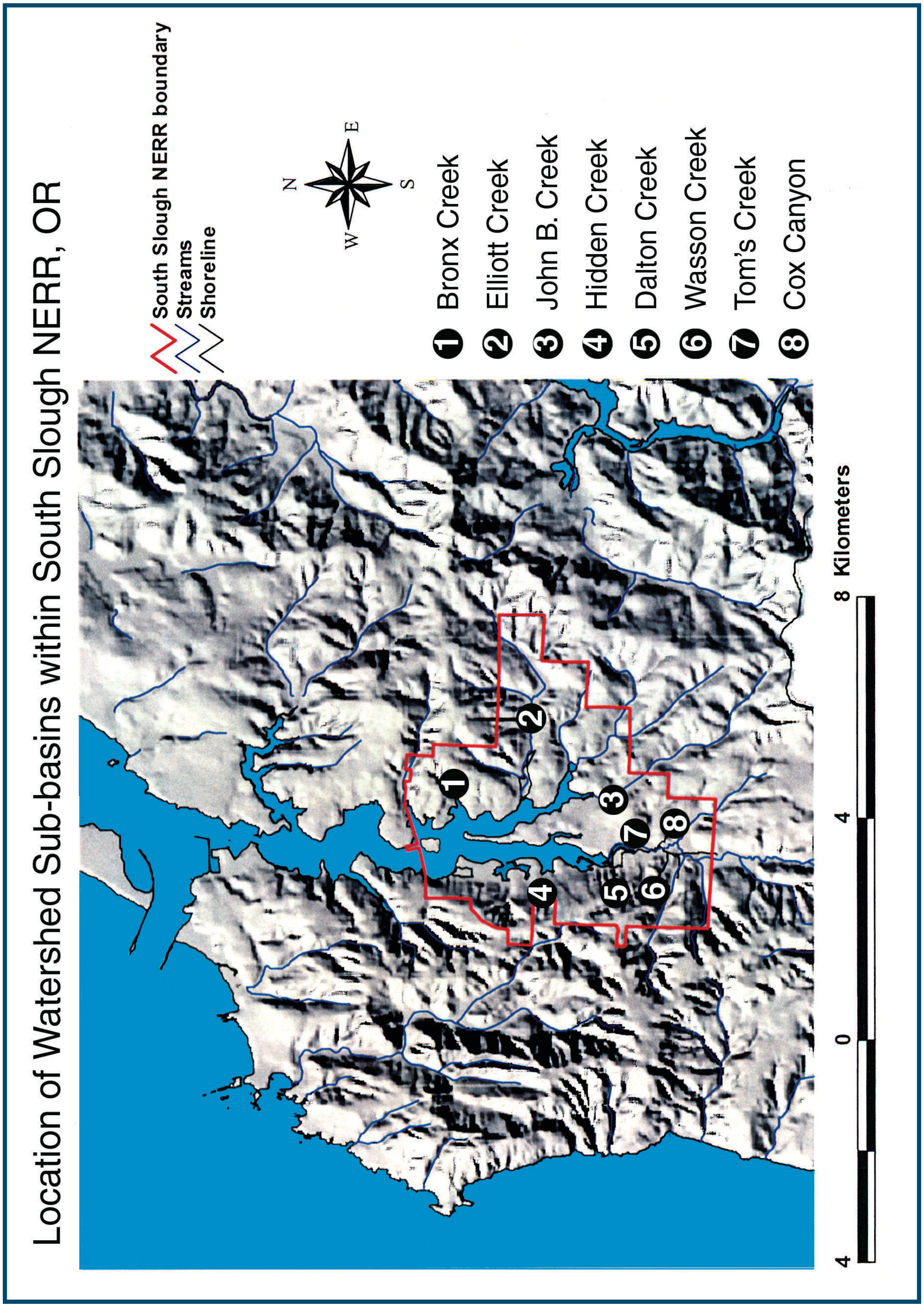


Figure 4.1. Location of eight watershed sub-basins surveyed during assessment of riparian habitats, South Slough NERR, OR.

of the freshwater streams, and Sheridan (2001) provided a summary of floral and faunal communities that inhabit riparian habitats in the coastal South Slough watershed.

4.2.2 Geomorphology of Freshwater Streams and Habitats

The South Slough estuary cuts through the steep and rugged Oregon Coast Range within the boundaries of the South Slough NERR and results in formation of drowned river valleys and dissected riparian hillslopes. Lower reaches of the perennial streams are influenced by the tide, and the unconstrained meandering drainage systems include numerous ponds and emergent freshwater marshes (Stone, 1987). These riparian habitats are characterized by low stream gradients, multiple bank terraces, braided stream channels, wide floodplains, broad riparian zones, beaver activity, and plant assemblages that are adapted to moist valley floors. In contrast, the upper reaches of the watershed streams are typically constrained within steep and narrow valleys characterized by higher gradients, singular (non-braided) stream channels, and vegetation assemblages that are similar to adjacent upland habitats. Upper reaches of the perennial streams and intermittent creeks are subject to episodic disturbance by infrequent hillslope failures and fluvial restructuring.

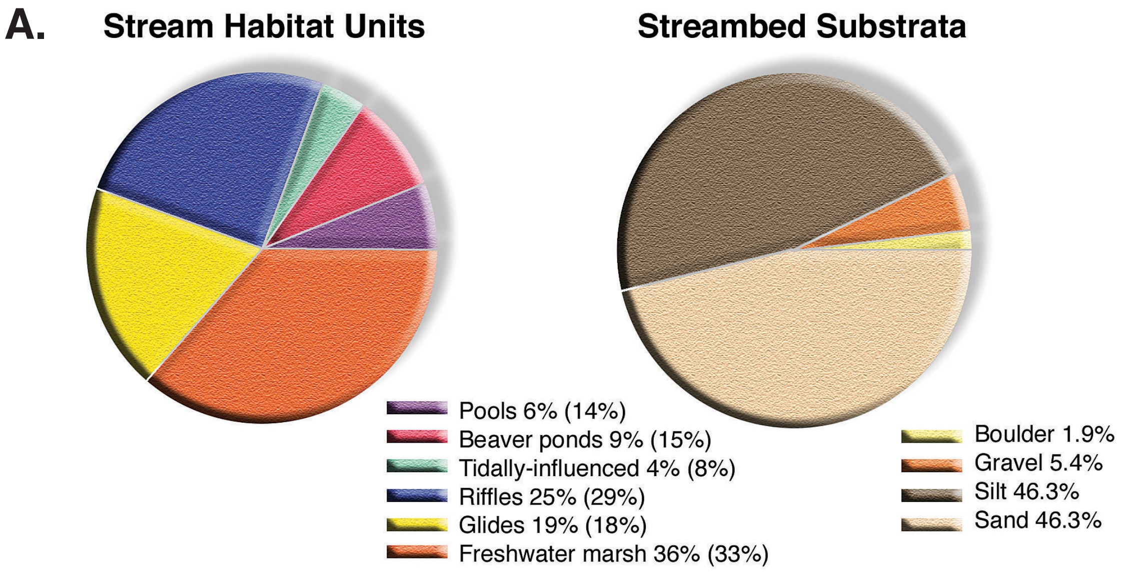
Freshwater discharge from the 2nd and 3rd order creeks within the South Slough NERR are fed by numerous smaller tributaries and springs. Discharge volumes are generally low in the higher order systems and average 1.3 cfs (SD: 0.8 cfs; Sheridan 2001). Stream gradients are also low (mean 3.3%, 95% CI: 1.9, 4.7%) in comparison with other locations in the Oregon Coast Range. Only a few stream reaches within the Reserve achieve average slopes over 5%, although short rock chutes and steep rock steps are present in the upper tributaries of most stream systems. Hillslopes adjacent to the streams are often much steeper (see Figure 2.15).

During the early 20th century, mature forests were harvested from the hills and valley floors within the South Slough watershed. In many cases the streambeds were used as primary skid trails to extract timber. The combined effect of eroded slopes and scarified stream channels has historically resulted in high sediment loads and substantial debris flows. In several instances the primary stream channel was completely buried under sediment. Harvest practices on commercial and public timberlands are now governed by the Oregon Forest Practices Act and typically produce smaller clear-cuts that are accompanied by riparian buffers.

Sand and silt are the dominant substratum in over 90% of the South Slough NERR stream habitats (Figures 2.16 and 4.2). Lower and middle reaches are typically dominated by sand, silt and vegetation. Larger sediment particle sizes (gravel, cobble, boulder) occur at much lower frequencies and are principally found only in the higher order tributaries. Dominance of the South Slough NERR streambeds by sediments with small particle sizes is at a level over twice that considered as undesirable for low gradient coastal sedimentary fluvial systems under the current Oregon Department of Fish and Wildlife benchmarks for stream channels and riparian habitats (Moore *et al.*, 1999).

Emergent freshwater marsh dominates the geomorphology of many stream banks in the South Slough NERR (Figure 4.2). Riffles are prominent in the 1st and 2nd order streams high in the watershed sub-basins, while 3rd and 4th order systems lower in the watershed contain numerous stretches of shallow slowly moving water (glides). Pool habitat (principally beaver ponds) constitutes less than 20% of all stream lengths in the Reserve. The frequency of pools within the South Slough NERR is currently below levels considered as desirable for salmonid habitat (Moore *et al.*, 1999).

Predominance of freshwater marshes in the South Slough NERR has a direct influence on the abundance of coarse woody debris and the extent of stream shade. Both the riparian forest floor (gallery) and instream habitats contain relatively low amounts of downed wood in comparison with other riparian systems. Stream reaches within the Reserve averaged only 81 pieces of downed wood km^{-1} (Table 4.1). In contrast, Bilby and Ward (1991) observed far more than 100 pieces km^{-1} within comparable second-growth riparian systems in southwestern Washington. Paucity of downed wood in the South Slough NERR has numerous ecological consequences within riparian habitats, including limited development of complex fish habitat and decreased nurse-log microhabitat for the establishment of shade-tolerant riparian conifers. Direct shading of the stream systems currently averages less than 45% within the South Slough NERR and is considered as undesirable under ODFW benchmarks (Moore *et al.*, 1999).



B.

Streambed Watershed position	Boulder	Gravel	Silt	Sand
Lower Reaches	0	0.8	92.4	6.9
Middle/ Upper Reaches	0	0.9	14.7	84.4
Tributaries	8.2	20.6	11.0	60.3
Stream Habitat Unit				
Beaver Pond	0	0	1.4	17.1
Tidally-influenced backwater pool	0	0	3.5	0
Glide	66.7	0	76.6	55.0
Pool	16.7	100.0	18.6	25.0
Riffle	16.7	0	0	2.9

Figure 4.2. Composition of freshwater stream habitat units and streambed substrata within the South Slough NERR, OR. A) Values indicate mean frequencies (SD) for stream habitat units and total frequencies for streambed substrata. B) Comparison of streambed substrata frequencies (%) at different watershed positions and within stream habitat units.

Low levels of overstory vegetation, however, probably do not contribute to stream water temperatures that are prohibitive for juvenile salmonids. Summer stream temperatures in the South Slough NERR averaged 11.9° C (95% CI: 7.6° C, 16.2° C; Denike *et al.*, 1992).

4.2.3 Riparian Vegetation

Vegetation that grows within the streamside riparian zone and adjacent hillslopes provides a principal source of nutrients for streams within the South Slough NERR. In addition, the riparian vegetation community buffers local climatic changes and provides a supply of downed wood for development of in-stream structures and increased streambed complexity. Riparian vegetation is also essential for development and support of stream bank terrace habitats, and for the provision of wildlife forage areas and dispersal corridors.

Composition of riparian vegetation communities is shaped within coastal watersheds by the processes of fluvial and geomorphic disturbances, fire, wind, competition, herbivory, and the history of human land-use practices (Naiman *et al.*, 1992). Natural disturbance processes are not addressed further by this summary, although they can play an important ecological role over long time scales (Agee, 1993). Over the past century, land-use disturbances within

Table 4.1. Stream canopy cover and levels of downed wood (SD) within South Slough NERR, OR. Sample size is number of 1/4 stream reaches (from Stone, 1987; and Sheridan, 2001).

Variable	Lower Reaches	Middle Reaches	Tributaries	Total
Sample size	6	10	11	27
Stream Canopy Cover (%)	37.3 (24.1)	44.4 (25.0)	49.3 (18.6)	44.8 (22.0)
No. downed wood / reach	39.7 (52.9)	61.8 (52.4)	60.6 (62.5)	56.4 (55.5)
No. downed wood / km	52.9 (63.8)	76.6 (54.4)	100.3 (59.3)	81.0 (59.2)

the riparian habitats of the South Slough NERR have included removal of overstory vegetation, anthropogenic fires, establishment of road systems, splash damming, and modification of riparian zones for agriculture and grazing (Sheridan, 2001). Most riparian areas within the Reserve have been disturbed by full or partial removal of overstory vegetation over the past 50 years. Three of eight drainage systems studied by Denike *et al.*, (1992) have been modified for livestock grazing by channelization of the streambed, construction of drainage ditches and earth dikes, and installation of tidegates. These land-use modifications provide an historical context for development of riparian floral and faunal communities within the South Slough NERR.

Table 4.2. Species composition of coniferous and deciduous tree communities within riparian habitats in South Slough NERR, OR. Values indicate mean basal area coverage (SD) and percent of total basal area contributed by trees for the lower, middle/upper, and tributary regions of streams (from Denike *et al.*, 1992; sample size = 152 plots).

	BASAL AREA m²/ha				TOTAL BASAL AREA %			
	Lower	Middle/ Upper	Tributary	Total BA	Lower	Middle/ Upper	Tributary	Total %
Sample size	46	43	63	152				
CONIFERS								
Port-Orford-cedar *Chamaecyparis lawsoniana*	0.2 (1.0)	0.1 (0.7)	1.4 (3.5)	0.7 (2.4)	2.1	0.5	5.2	3
Sitka spruce *Picea sitchensis*	5.0 (9.7)	5.3 (7. 6)	6.1 (8.8)	5.6 (8.7)	53.2	24.6	23.7	28
Douglas-fir *Pseudotsuga menziesii*	0.3 (1.5)	0.6 (1.6)	0.7 (1.9)	0.6 (1.7)	3.2	3.0	2.8	3
Western redcedar *Thuja plicata*	0 (0)	0 (0)	0.2 (0.8)	0.1 (0.5)	0	0	0. 6	<1
Western hemlock *Tsuga heterophylla*	0.2 (1.0)	1.6 (4.8)	4.1 (8.1)	2.2 (6.0)	2.1	7.4	15.9	11
DECIDUOUS TREES								
Big-leaf maple *Acer macrophyllum*	0.3 (1.5)	0 (0)	0 (0)	0.1 (0.8)	3.2	0	0	<1
Red alder *Alnus rubra*	3.1 (7.4)	12.7 (14.1)	12.0 (13.0)	9.5 (12.6)	33.0	58.2	46.5	48
Western crabapple *Pyrus fusca*	0 (0)	0.6 (4.2)	0 (0)	0.2 (2.2)	0	3.0	0	1
Cascara buckthorn *Rhamnus purshiana*	0.3 (2.0)	0.3 (1.2)	1.4 (5.2)	0.8 (3.6)	3.2	1.5	5.4	4
Red elderberry *Sambucus racemosa*	0 (0)	0.4 (2.8)	0 (0)	0.1 (1.5)	0	2.0	0	1
Totals/position	9.4	21.7	25.9					
Hardwoods (Total)				10.7 (13.6)				54%
Conifers (Total)				9.1 (12.1)				46%

4.2.3.a Riparian Cover Types and Overstory Vegetation

Riparian habitats within the South Slough NERR are dominated by stream reaches characterized by stands of hardwood trees, mixed conifer / hardwood forests, and open-canopy freshwater marshes (Figure 4.2, Tables 4.2). Conifer-hardwood cover types encompass nearly 50% of the riparian areas surveyed within the Reserve, and exclusive hardwood cover accounts for over 20% of the sampled areas. Over 25% of the riparian habitats are composed of freshwater marshes. Riparian habitats that contain exclusively coniferous trees, pasture-grasses, and brush make up less than 8% of the total riparian areas within the Reserve (Table 4.3).

Conifers and deciduous trees dominate the riparian valley floors in the South Slough NERR (Table 4.2). Basal area (BA) of deciduous trees in the riparian areas averaged 10.7 $m^2 ha^{-1}$ while the BA for conifers averaged 9.1 $m^2 ha^{-1}$. These basal area estimates are far lower than previously reported values for comparable riparian areas in other locations within the Oregon Coast Range (Pabst and Spies, 1999). Red alder (*Alnus rubra*) and Sitka spruce (*Picea sitchensis*) are the most frequently encountered overstory species in the riparian habitats (Table 4.2). Sitka spruce are very abundant along the banks of higher-order streams at locations that are low within the watershed sub-basins. In contrast, red alder is much more common in the middle reaches and tributaries where it contributes twice the basal area of Sitka spruce, four times the basal area of western hemlock (*Tsuga heterophylla*), and an order of magnitude greater basal area than the other species of trees (Table 4.2).

Several other species of trees occur at low densities in the South Slough NERR. For example, big-leaf maple (*Acer macrophyllum*) occurs principally in lower stream reaches, and western hemlock is much more frequent at higher elevations in the tributaries. Port-Orford-cedar (*Chamaecyparis lawsoniana*), western redcedar (*Thuja plicata*) and Douglas-fir (*Pseudotsuga menziesii*) are rare throughout South Slough NERR riparian areas (Denike *et al.*, 1992). Species richness of overstory vegetation within the South Slough NERR was similar to that described for other Oregon Coast Range sites (Pabst and Spies, 1999), although several species commonly observed elsewhere did not occur in the Reserve survey, including grand fir (*Abies grandis*), Pacific yew (*Taxus brevifolia*), California laurel (*Umbellularia californica*), Oregon ash (*Fraxinus latifolia*), and tanoak (*Lithocarpus densiflorus*).

Riparian overstory habitats within the South Slough NERR include: (a) constrained stream reaches and tributaries with densely stocked, closed-forest canopies, and (b) freshwater marsh stream reaches with poorly stocked, open-forest canopies (Table 4.4). Canopy cover in terrestrial riparian habitats averages 60.4% and is comparable to other locations in the Oregon Coast Range (Pabst and

Table 4.3. Vegetation cover types within riparian overstory communities in the South Slough NERR, OR. Data sets collected from eight randomly selected riparian zones (from Denike *et al.*, 1992).

Vegetation Cover Type	Code	Hectares in sample population	Percent of riparian areas sampled
Brush	BR	0.45	0.5%
Conifer	C	2.32	2.8%
Conifer/Hardwood-Intermediate	CHW2	23.26	28%
Conifer/Hardwood-Large	CHW3	14.67	17.7%
Freshwater Marsh	FM	22.23	26.7%
Hardwood-Intermediate	HW2	14.93	18%
Hardwood-Large	HW3	1.87	2.2%
Diked / Pasture Grass	PG	3.38	4.1%
Total		83.12	

Table 4.4. Characteristics of riparian overstory communities within the South Slough NERR, OR. Open canopy habitats include freshwater marsh, diked pasture grass, and brush dominated riparian zones; closed canopy habitats include all forested riparian areas. Sample size varies by overstory parameter, from 10 (site tree data in lower reaches) to 63 (tributary data; from Denike *et al.*, 1992).

			Watershed Position			
Overstory Parameter	**Open Canopy (95%C.I.)**	**Closed Canopy (95%C.I.)**	**Lower (SD)**	**Middle/ Upper (SD)**	**Tributaries (SD)**	**Totals (SD)**
Canopy Cover %	5.9	86.5	31.2	65.6	83.1	60.4
	(2.5, 9.3)	(83.0, 90.0	(40.8)	(38.5)	(23.2)	(40.8)
Basal Area m^2/ha	1.5	27.2	9.4	21.7	25.9	19.7
	(0.5, 2.4)	(24.3, 30.0)	(14.6)	(17.8)	(15.6)	(17.4)
Conifer BA m^2/ha	1.2	12.3	5.7	7.7	12.5	9.1
	(0.3, 2.0)	(9.8, 14.8)	(11.1)	(10.5)	(13.0)	(12.1)
Hardwood BA m^2/ha	0.3	14.9	3.7	14.1	13.4	10.7
	(-0.2, 0.8)	(12.2, 17.5)	(8.4)	(16.1)	(13.0)	(13.6)
Dia. at Breast Ht. cm	50.1	45.4	53.2	46.9	42.6	45.7
	(29.0, 71.2)	(41.7, 49.1)	(18.8)	(8.3)	20.5)	(19.8)
Trees Per Hectare	24.4	498.8	83.2	446.2	506.9	361.5
	(-3.9, 52.7)	(362.9, 634.7)	(165.1)	(920.1)	(564.0)	(639.3)
Overstory Age yrs			72.5	1.5	49.9	
				(53.9)	(38.9)	(29.2)
Overstory Ht. meters			33.3	31.4	31.0	
			(6.2)	(9.4)	(6.8)	

Spies, 1999). Riparian areas within the Reserve average 362 trees ha^{-1}. These riparian habitats lack significant regeneration of understory vegetation, and they are covered primarily by pole-stage red alder and less frequently by large-butted Sitka spruce. Riparian tree diameters average 45.7 cm and median tree diameter is 39 cm. Site potential trees in the riparian overstory had an average height of 31.6 m (95% CI: 29.4-33.7 m). The average age of site potential trees in the study population was 54.9 years (95% CI: 44.1-65.7 yrs). This range of stand ages is consistent with the last major episode of timber harvests and stand removal (1950's) in areas that are currently encompassed by the South Slough NERR.

4.2.3.b Riparian Shrubs

Significant portions of stream bank terraces and floodplains in riparian zones of the Oregon Coast Range are devoid of trees and exist as bank habitats that are dominated by shrub vegetation. Dominance of tall shrubs in the Coast Range riparian forests represents an important biotic control mechanism that regulates the composition of herb communities and tree regeneration. Seventeen species of shrubs were identified in the eight riparian systems surveyed by Denike *et al.* (1992) within the South Slough NERR. This level of species richness for shrubs is comparable to observations for other locations in the Oregon Coast Range (Pabst and Spies, 1998).

Riparian shrub communities within the South Slough NERR are dominated by salmonberry (*Rubus spectabilis*; Table 4.5), and this species is present in over 70% of forested riparian areas. No shrub species has a frequency over 5% in the open habitats dominated by freshwater marsh herbaceous communities. Salmonberry reaches its highest density in intermediate-height hardwood sites. Mesic upland shrubs such as salal (*Gaultheria shallon*), evergreen huckleberry (*Vaccinium ovatum*) and red huckleberry (*V. parviflorum*) exhibit greater densities in the riparian habitats of the South Slough NERR compared to hydric species like willow (*Salix* spp.) and black twinberry (*Lonicera involucrata*). Shrub communities are about six times more abundant in closed-canopy riparian habitats compared to open-canopy habitats (Table 4.6).

Table 4.5. Riparian shrub community within the South Slough NERR, OR. Values indicate mean abundance (SD) on a relative scale between 0 absent and 6 very abundant (adapted from Denike *et al*., 1992).

Shrub Species	Common Name	Lower	Middle/Upper	Tributaries	Total
	Sample size	46	42	52	140
Acer circinatum	Vine maple	0 (0.2)	0.4 (0.9)	0.2 (0.7)	0.2 (0.7)
Gaultheria shallon	Salal	0.5 (1.1)	0.6 (1.0)	1.2 (1.3)	0.8 (1.2)
Holodiscus discolor	Oceanspray	0 (0)	0.1 (0.3)	0 (0.3)	0 (0.2)
Lonicera involucrata	Black twinberry	0.1 (0.5)	0.1 (0.3)	0 (0)	0.1 (0.3)
Menziesia ferruginia	Mock azalea	0 (0.3)	0 (0)	0 (0.3)	0 (0.2)
Myrica californica	Wax myrtle	0.2 (0.5)	0 (0)	0 (0.1)	0.1 (0.3)
Rhododendron macrophyllum	Pacific rhododendron	0.1 (0.3)	0.1 (0.3)	0.1 (0.5)	0.1 (0.4)
Rhododendron occidentale	Western azalea	0 (0)	0.2 (0.5)	0.1 (0.2)	0.1 (0.3)
Ribes bracteosum	Stink currant	0.4 (0.8)	0.5 (0.9)	0.2 (0.7)	0.3 (0.8)
Rubus spp.	Berries	0 (0.2)	0.1 (0.3)	0 (0)	0 (0.2)
Rubus armeniacus	Himalayan blackberry	0 (0)	0.1 (0.3)	0 (0)	0 (0.2)
Rubus parviflorus	Thimbleberry	0.1 (0.3)	0.1 (0.3)	0.2 (0.7)	0.1 (0.5)
Rubus spectabilis	Salmonberry	0.9 (1.3)	2.5 (1.4)	2.9 (1.3)	2.1 (1.6)
Salix spp.	Willows	0.1 (0.4)	0.1 (0.6)	0 (0.1)	0.1 (0.4)
Sambucus racemosa	Red elderberry	0.5 (1.1)	0.7 (1.2)	0.7 (1.1)	0.6 (1.1)
Vaccinium ovatum	Evergreen huckleberry	0.5 (1.0)	0.7 (1.0)	1.5 (1.4)	0.9 (1.2)
Vaccinium parviflorum	Red huckleberry	0.3 (0.8)	0.5 (0.8)	0.9 (1.1)	0.6 (0.9)

Table 4.6. Differences in shrub frequencies (95% C.I.) between open and closed canopy riparian habitats within the South Slough NERR, OR. Open canopy habitats include freshwater marsh, diked pasture grass areas, and brush-dominated riparian zones; closed canopy habitats contain all forested riparian habitats. See Table 4.5 for common names.

Shrub Species	Open Canopy	Closed Canopy
Gaultheria shallon	2% (-2, 7%)	16% (8, 23%)
Rubus spectabilis	2% (-2, 7%)	7% (6, 79%)
Vaccinium ovatum	0	19% (11, 27%)
Vaccinium parviflorum	2% (-2, 7%)	6% (1, 11%)
Frequency of any shrub species > "occasional"	2% (-2, 7%)	82% (75, 90%)
Sample Size	44	96

4.2.3.c Herbaceous Riparian Plants

Hebaceous communities within the South Slough NERR are composed largely of broad-leaved forbs and graminoids (Table 4.7). Species assemblages of herbaceous plants differ substantially between the open- and closed-canopy riparian habitats. The most frequently occurring herbaceous plants in the closed-canopy riparian habitats include mesic species like western sword fern (*Polystichum munitum*), deer fern (*Blechnum spicant*) and lady fern (*Athyrium filix-femina*), and species that are well-adapted to hydric-moist conditions such as skunk cabbage (*Lysichiton americanum*). Conversely, the open-canopy riparian herbaceous communities are dominated by slough sedge (*Carex obnupta*), reed canarygrass (*Phalaris arundinacea*), and small-fruited bulrush (*Scirpus microcarpus*). Co-occurrence of these species is indicative of the tightly juxtaposed

Table 4.7. Comparison of herbaceous plant communities in open and closed riparian habitats (95% C.I.). Average plot frequency and abundance are presented for the five most frequently occurring species in each canopy class. Open canopy habitats include freshwater marsh, diked pasture grass areas, and brush-dominated riparian zones. Closed canopy habitats include all forested riparian habitats.

Species	Common name	Frequency	Abundance
Open Canopy			
Carex obnupta	Slough sedge	0.6 (0.4, 0.7)	1.9 (1.4, 2.4)
Scirpus microcarpus	Small-fruited bulrush	0.6 (0.4, 0.7)	1.7 (1.2, 2.1)
Phalaris arundinacea	Reed canary grass	0.5 (0.4, 0.7)	1.8 (1.2, 2.4)
Lotus corniculatus	Birdfoot trefoil	0.4 (0.3, 0.6)	1.2 (0.8, 1.7)
Lysichiton americanum	Yellow skunk cabbage	0.4 (0.2, 0.5)	1.0 (0.7, 1.4)
Species Richness:	7.0 (6.1, 7.9)		
Closed Canopy			
Polystichum munitum	Western sword fern	0.8 (0.7, 0.8)	2.4 (2.1, 2.7)
Lysichiton americanum	Yellow skunk cabbage	0.6 (0.5, 0.7)	1.8 (1.5, 2.1)
Athyrium filix-femina	Lady fern	0.6 (0.5, 0.7)	1.5 (1.2, 1.7)
Blechnum spicant	Deer fern	0.6 (0.5, 0.7)	1.7 (1.4, 2.1)
Tolmiea menziesii	Pig-a-back plant	0.3 (0.2, 0.4)	0.8 (0.6, 1.1)
Species Richness:	5.4 (4.8, 6.1)		

nature of stream bank terrace, floodplain and hillslope surfaces in these small coastal riparian systems. Western sword fern is the most abundant herbaceous species in the South Slough NERR riparian areas (Table 4.7). The eight most frequently observed species identified by Pabst and Spies (1998) were included in the top 13 most abundant species in the Reserve riparian habitats (Sheridan, 2001). Notable differences include the high frequency of false lily-of-the-valley (*Maianthemum dilatatum*) and skunk cabbage in South Slough, and the low frequency of crisp sandwort (*Stellaria crispa*).

Patterns of herbaceous vegetation are structured in riparian zones by fluvial and hillslope disturbances, microclimate, herbivory, and anthropogenic disturbance. These processes produce a level of diversity in the composition of herb communities in valley floors that is significantly higher than adjacent hillslope areas (Gregory *et al.*, 1991; Pabst and Spies, 1998). A total of 114 species of plants were observed within the South Slough NERR riparian areas, including 10 trees, 17 shrubs, and 87 species of herbaceous plants (Denike *et al.*,1992). Shannon-Wiener indices of diversity for this assemblage of herbaceous plants averaged 2.88 (0.64 SD) at the watershed level and were comparable to other studies of riparian communities in the Pacific northwest bioregion (Schoonmaker and McKee, 1988; Pabst and Spies, 1998).

4.2.3.d Riparian Vegetation Communities

Diverse plant communities in the South Slough NERR riparian habitats can be assembled into cohesive units by the combination of species associations, uniquely-derived species groups (cluster analysis), and ordination of datasets for herbaceous species. Sheridan (2001) applied plant associations developed for the Siuslaw National Forest (coastal Oregon; Christy *et al.*, 1998) to datasets generated within the riparian habitats of the South Slough NERR. Over 60% of the forested riparian areas in the Reserve fall into the *Alnus rubra / Rubus spectabilis / Carex obnupta - Lysichiton americanum* association. This floral association of forested wetland plants is mid-seral in development within the nearby Siuslaw National Forest, and the community members occur primarily on perennially-saturated stream terraces in association with narrow stream valleys. The forested wetland association also includes several additional species that are well represented in the South Slough NERR including crab apple (*Malus fusca*), false lily-of-the-valley, black twinberry and cascara (*Rhamnus purshiana*). Other species associations developed previously by Christy *et al.* (1998) to describe forested, shrubland and open herbaceous communities were not representative of the South Slough assemblages (Sheridan 2001).

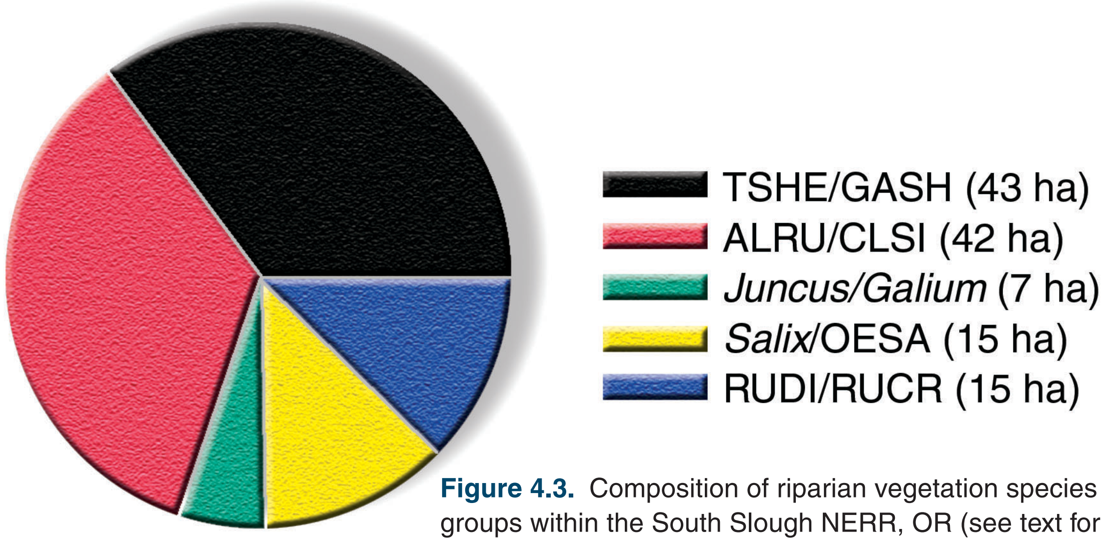


Figure 4.3. Composition of riparian vegetation species groups within the South Slough NERR, OR (see text for identification of species groups).

Surveys of vegetation plots were used to identify two distinct closed-canopy and three open-canopy riparian communities (Figures 4.3 & 4.4). Sheridan (2001) carried out cluster analysis to reveal that the closed-canopy forested species groups accounted for 85% of the spatial cover in riparian areas. Closed-canopy forested species assembalges include the *Tsuga heterophylla / Gaultheria shallon* (TSHE/GASH) group and the *Alnus rubra / Claytonia siberica* (ALRU/CLSI) group (Figure 4.3). The TSHE/GASH group includes several relatively xeric plants and a limited number of forbs, and is broadly representative of hillslope and tributary habitats within the South Slough NERR. The TSHE/GASH species group also includes overstory trees such as western hemlock and Port-Orford-cedar, and a few ericaceous shrubs. In contrast, the ALRU/CLSI group represents the typical moist Oregon Coast Range riparian terrace community. This species group is typified by a dense overstory of red alder trees that provide protection for an assemblage of shade-tolerant forbs (*i.e.,* Siberian candyflower, *Claytonia sibirica*; Mexican betony, *Stachys mexicana*) and hillslope-associated species including sword fern and lady fern.

Open-canopy species groups identified within the South Slough NERR include the *Juncus / Galium, Salix / Oenanthe sarmentosa* (*Salix*/OESA) and R*ubus discolor / Rumex crispus* (RUDI/RUCR) groups (Figure 4.3). The *Juncus / Galium* group includes moisture-tolerant species associated with frequently inundated habitats, often in the lower portion of the watershed near the head of tide. This species group includes hydric species like rushes (*Juncus* spp.) and bur-reed (*Sparganium emersum*). The *Salix*/OESA group is indicative of riparian freshwater wetlands that support woody vegetation (*e.g.,* willow and black twinberry), and hydric forbs including water parsley (*Oenanthe sarmentosa*) and small-fruited bulrush (*Scirpus microcarpus*). Finally, the RUDI/RUCR group is typical of open habitats and includes opportunistic disturbance species like Himalayan blackberry (*Rubus discolor*), curly dock (*Rumex crispus*), white clover (*Trifolium repens*), and several graminoids as well as wetland species such as slough sedge (*Carex obnupta*) and common rush (*Juncus effusus*).

The five species groups identified by Sheridan (2001) appear to adequately represent community types visible on the ground within South Slough NERR riparian habitats, and they provide a superior tool for future descriptions of riparian species associations. These plant assemblages divide environmental space differently than the ten species groups identified previously for coastal riparian communities (Pabst and Spies, 1998). Open-canopy riparian species are much more frequent in the South Slough NERR, and species groups that are commonly associated with gravel bars, seeps, and hillslope habitats are generally missing from riparian communities in the Reserve. The ALRU/CLSI species group identified within the South Slough NERR incorporates community elements of the *Tolmiea menziesii, Rubus spectabilis* and *Polystichum munitum* groups described by Pabst and Spies (1998).

Sheridan (2001) used non-metric multidimensional scaling as an ordination technique to further clarify dominant patterns in riparian species assemblages within the South Slough NERR, and to investigate environmental drivers of community structure (Figure 4.4). Two-dimensional ordination of vegetation plots in species-space captures almost 84% of the total plot variance. In the ordination analysis, the Axis-1 gradient represents the spatial transition from vegetation communities that require open-canopy conditions to communities dominated by closed-canopies. The Axis-2 gradient is weakly related to moisture requirements and describes variance in moisture tolerance that is not captured along Axis-1 (Figure 4.4).

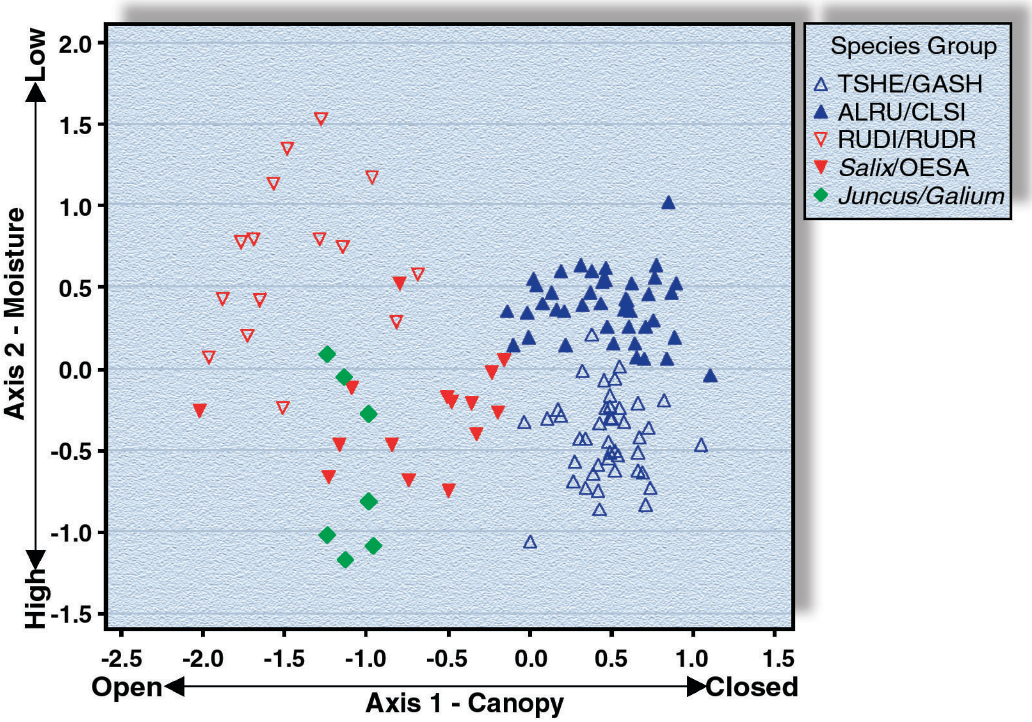


Figure 4.4. Ordination of vegetation species groups along two environmental gradients. Axis 1 indicates location along gradient of open to closed forest canopies; Axis 2 indicates location along high to low moisture gradient. (Data collected by Denike *et al.*, 1992).

The five riparian vegetation species assemblages found within South Slough NERR are clearly separated by the ordination gradients of forest canopy cover and moisture (Figure 4.4). The position of particular species in ordination space highlights their spatial proximity in the environmental space defined by riparian areas of the Reserve. For example, groups of closed-canopy forest riparian species (*i.e.,* TSHE/GASH and ALRU/CLSI) are tightly clustered and distinct from the more widely separated open-canopy species groups. Conversely, the open-canopy species groups (*i.e.,* RUDI/RUCR and *Juncus / Galium*) are clearly differentiated from each other and from the closed-canopy species groups. In particular, the opportunistic RUDI/RUCR species assemblage is far removed from other species groups. The *Salix* / OESA species group is intermediate in canopy closure and moisture levels, and appears centrally in ordination space. Strong correlations between community composition and canopy cover, coupled with separation of riparian assemblages from dry and wet sites, provide a quantitative measure of the degree to which vegetation overstory (and to a lesser extent moisture and disturbance regime), determine the characteristics of riparian vegetation communities within the South Slough NERR.

4.2.3.e Freshwater Marsh and Diked Habitats

The spatial extent of freshwater marsh habitat is substantial in most riparian systems within the Oregon Coast Range. In the small and steep South Slough coastal watershed, however, open-canopy reaches of emergent freshwater marsh may constitute a significant portion of the total riparian zone (Figure 4.2). Freshwater marsh and diked riparian habitats exhibit distinctive properties that have not been well described, including low stream gradients and braided, ill-defined channels. Substantial riparian communities also develop along the linear drainage ditches in diked marsh and pasture areas.

Densities of overstory trees are dramatically different between open- and closed-canopy riparian habitats in the South Slough NERR (Table 4.4). Measurements of tree basal area, canopy cover, and density of overstory trees (# ha^{-1}) are all significantly lower in open-canopy sites. Large Sitka spruce trees sometimes extend over the open riparian areas from the margins of stream banks and provide nominal contributions of tree basal area. Structural characteristics that are typically associated with the overstory community, including fallen branches, logs, snags, and shade are all reduced in the freshwater marshes.

Open-canopy riparian habitats within the South Slough NERR support only negligible densities of shrubs (Table 4.6). The frequency of occurrence for shrub species in open habitats is less than 5%. In contrast, closed-canopy riparian habitats support shrub cover in over 80% of sites sampled. Open-canopy sites support species assemblages of shrubs that are similar to those observed in closed-canopied habitats, but they are inhabited by higher densities of willow (*Salix*) and low densities of red elderberry (*Sambucus racemosa*).

Communities of herbaceous plants are dominated in the open riparian habitats of the South Slough NERR by several species of emergent wetland plants (Table 4.7). Slough sedge (*Carex obnupta*), small-fruited bulrush (*Scirpus microcarpus*) and reed canary grass (*Phalaris arundinacea*) are associated with high water tables and frequent flooding. Species richness of herbaceous plants is significantly greater in the open freshwater marshes compared with the closed forested riparian habitats. Elevated biotic diversity in the marshes can be attributed to the occurrence of hydrophytes and other species that are adapted to conditions of higher light intensity. In locations where diking and channelization of streams have historically occurred within the Reserve to promote drainage, the freshwater marshes become dominated by the *Rubus discolor / Rumex crispus* (RUDI/RUCR) species group. This community type is characterized by minimal overstory and shrubs, and includes a principal mixture of opportunistic non-indigenous grasses and herbaceous plants.

4.2.4 Riparian Faunal Assemblages

Riparian habitats provide significant food resources, patch diversity, and steep gradients of substrate, microclimate, and energetic resources for many species of aquatic and riparian-dependent terrestrial animals (Gregory *et al.*, 1991). Diverse communities of aquatic insects occur within the streams and riparian habitats. Vertebrate faunal assemblages that inhabit riparian habitats within the South Slough NERR include mammals, fishes, amphibians, reptiles, and birds. Mammal populations have not been adequately surveyed in the South Slough NERR, although their presence and ecological impact on riparian habitats is recognized. American beaver (*Castor canadensis*) is a dominant landscape engineer in riparian areas of the Reserve. In addition, Roosevelt elk (*Cervus elaphus roosevelti*) and Columbian black-tailed deer (*Odocoileus hemonius columbianus*) also make extensive use of riparian corridors, and they transform these areas through grazing and movement along established game trails.

4.2.4 a Aquatic Insects and Invertebrates

Aquatic insects and invertebrate communities have not been systematically surveyed within the riparian habitats of the South Slough NERR. Preliminary surveys, however, demonstrate that diverse communities of aquatic insects occur within the streams and riparian habitats of the Reserve, including 10 orders, 55 families, and over 80 genera of aquatic insects (Table 4.8). True flies (Diptera: 13 families, 19 genera) are abundant as both adults and larvae where they provide an important prey resource for freshwater fish. Beetles (Coleoptera: 12 families, 18 genera) and caddisflies (Trichoptera: 10 families, 19 genera) are also particularly diverse in the Reserve streams where they process leaf litter and organic debris that accumulate in the slowly moving water of pools and glides. Downed wood creates obstructions and pools in the streams, and immature dragonflies, stoneflies, caddisflies, and mayfly nymphs feed on algae, leaf litter and rotting wood where they are important ecological elements of the stream community (Maser and Sedell, 1994). The streams and riparian habitats are also inhabited by several crustaceans including amphipods, isopods, and decapod crayfish (*i.e., Pacifastacus*) and molluscs (snails, slugs, and freshwater clams; Table 4.8). Ants, bees, wasps, mosquitoes, spiders, mites, centipedes, millipedes, and a myriad of other insects and terrestrial invertebrates also inhabit the stream bank habitats and decaying vegetation in the riparian areas of the South Slough.

4.2.4.b Freshwater Fish Communities

Fish communities are tightly coupled to habitat conditions within streams and riparian zones in the Oregon Coast Range (Naiman *et al.*, 1992). Resolution of links between fish assemblages and environmental conditions in riparian areas requires consideration of several aquatic niche parameters and attributes of adjacent floodplains, bank terraces and hillslopes. Only seven species of fish have been

Table 4.8. List of aquatic insects and invertebrates observed in streams within the South Slough NERR, OR (from Denike et al., 1992; * indicates tentative identification of genus; taxonomic identifications from Pennak, 1978).

Phylum/Class/ Order	Family	Genus
ARTHROPODA		
Class Insecta		
O. Collembola	Entomobryidae	*Tomocerus*
Springtails	Sminthuridae	*Dicyrtoma*
O. Ephemeroptera	Baetidae	*Baetis*
Mayflies		*Callibaetis*
	Ephemerellidae	*Drunella*
	Heptageniidae	*Cinygma*
		Cinygmula
		Ironodes
	Leptophlebiidae	*Paraleptophlebia*
	Siphlonuridae	*Ameletus*
		Siphlonurus
O. Odonata	Aeshnidae	*Aeshna*
Dragonflies	Coenagrionidae	*Ischnura**
		*Zoniagrion**
O. Plecoptera	Chloroperlidae	
Stoneflies	Leuctridae	*Despaxia*
	Nemouridae	*Malenka*
		Nemoura
		Soyedina
	Peltoperlidae	*Yoraperla*
	Perlodidae	*Isoperla*
		*Kogotus**
O. Hemiptera	Belostomatidae	*Lethocerus*
True Bugs	Corixidae	*Sigara**
	Gerridae	*Gerris*
	Notonectidae	*Notonecta*
O. Megaloptera	Corydalida	*Orohermes*
Dobsonflies and Alderflies	Sialidae	*Sialis*
ARTHROPODA		
Class Insecta		
O. Trichoptera	Brachycentridae	*Micrasema*
Caddisflies	Calamoceratidae	*Heteroplectron*
	Hydropsychidae	*Parapsyche*
	Lepidostomatidae	*Lepidostoma*
	Limnephilidae	*Asynarchus*
		Chyranda
		Cryptochia
		Ecclisocosmoecus
		Glyphopsyche
		Limnephilus (spp.)
		Neophylax
		Moselyana
		Psychoglypha
		Pycnopsyche (spp.)
	Odontoceridae	*Nerophilus*
	Philopotamidae	*Wormalidia*
	Phryganeidae	*Agrypnia*
	Polycentropidae	*Cernotina*
	Rhyacophilidae	*Rhyacophilidae*
O. Coleoptera	Anthicidae	
Beetles	Carabidae	*Harpalus**
	Chrysomelidae	*Donacia*
	Curculionidae	*Hyperodes*
	Dytiscidae	*Agabus*
		Hydaticus
		Hydroporus
		Hygrotus
	Elmidae	*Lara*

Table 4.8 continued next page

Table 4.8. List of aquatic insects and invertebrates observed in streams within the South Slough NERR, OR (continued)

Phylum/Class/ Order	Family	Genus
ARTHROPODA		
Class Insecta		
O. Coleoptera	Gyrinidae	*Gyrinus*
Beetles	Haliplidae	*Haliplus*
(continued)	Hydrophilidae	*Enochrus*
		Helobata
		Helophorus
		Hydrobius
		Paracymus
		Tropisternus
	Scirtidae	*Scirtes*
	Staphylinidae	*Psephidonus*
	Tenebrionidae	
O. Diptera	AhtericidaeAtherix	
True Flies	Ceratopogonidae	
	Chaoboridae	*Eucorethra*
	Chironomidae	(several spp.)
	Culicidae	*Aedes*
		*Culex or Aedes**
		Wyeomyia
	Dixidae	*Dixa*
		Dixella
		Meringodixa
	Muscidae	*Limnophora**
	Psychodidae	
	Ptychopteridae	*Bittacomorpha*
		Ptychoptera
ARTHROPODA		
Class Insecta		
O. Diptera	Simuliidae	
True Flies	Stratiomyiidae	*Odontomyia*
(continued)	Syrphidae	
Tipulidae		*Cryptolabis**
		Dicranota
		Gonomyia
		Hexatoma
		Pedicia
		Prionocera
		*Tipula**
Class Crustacea		
O. Amphipoda	Gammaridae	*Gammarus*
	Talitridae	*Hyallela*
O. Decapoda	Astacidae	*Pacifastacus*
O. Isopoda	Asellidae	*Asellus*
	Sphaeromidae	*Gnorimosphaeroma*
MOLLUSCA		
Class Gastropoda		
O. Lymnophila	Ancylidae	*Ferrissia**
	Planorbidae	*Helisoma* (spp.)
O. Mesogastropoda	Hydrobiidae	*Hydrobia*
	Pleuroceridae	*Goniobasis*
O. Stylommatophora	Arionidae	*Ariolimax*
	Helminthoglyptidae	Monadenia
Class Pelecypoda		
O. Veneroida	Sphaeriidae	*Sphaerium*

Table 4.9. Fish densities in freshwater streams within the South Slough NERR, OR. Values indicate mean no. of individuals per km (SD) captured by Denike *et al.*, 1992).

		Watershed position (Sample Size)			
Species	**Common Name**	**Lower (6)**	**Middle (10)**	**Tributaries (15)**	**Total (31)**
Cottidae	Sculpin spp.	38.9 (31.0)	46.9 (42.8)	19.7 (61.5)	32.2 (51.3)
Gasterosteus aculeatus	Three-spined stickleback	15.7 (16.6)	0.4 (0.8)	3.2 (8.6)	4.7 (10.6)
Lampetra richardsonii	W. brook lamprey	0.8 (1.5)	5.6 (11.9)	1.8 (3.1)	2.8 (7.2)
Oncorhynchus clarki	Cutthroat trout	3.0 (6.5)	6.4 (10.1)	7.3 (23.9)	6.2 (17.5)
Oncorhynchus kisutch	Coho salmon	16.1 (30.2)	1.0 (1.8)	8.8 (14.9)	7.7 (16.9)
Unknown Salmonids		1.9 (3.1)	3.7 (6.8)	4.2 (8.4)	3.6 (7.0)
Unknown fish		0.2 (0.5)	0 (0)	0.1 (0.4)	0.1 (0.4)

identified in the freshwater streams of the South Slough NERR. These are: coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*O. clarki*), three-spine stickleback (*Gasterosteus aculeatus*), western brook lamprey (*Lampetra richardsonii*) and three species of sculpins (reticulate sculpin, *Cottus perplexus*; mottled sculpin, *C. bairdi*; pit sculpin, *C. pitensis*; Table 4.9). Sculpins are by far the most abundant group of fish in the freshwater streams where they occur at densities over twice that observed for salmonids (Denike *et al.*, 1992). Salmonids are second in abundance, while three-spine stickleback and western brook lamprey are present in the Reserve freshwater stream systems at lower densities. Fish assemblages within the South Slough watershed include species primarily associated with the low gradient, small substratum habitats that dominate the freshwater streams, and anadromous salmonids that require estuarine areas for rearing.

Salmonids play key roles in the freshwater stream communities of the Pacific northwest coastal region (Bisson *et al.*, 1988; 1992), and they are the focal species for considerable riparian conservation efforts (Johnson and O'Neil, 2000). Anadromous salmonids forage and rear in the South Slough NERR (Frank *et al.*, 1990; Miller and Sadro, 2000) and they spawn in the freshwater streams that drain into the tidal basin. Juvenile coho salmon and cutthroat trout are the most common salmonids within the South Slough NERR. Stone (1987) and Denike *et al.*, (1992) observed low densities of coho salmon and cutthroat trout (< 8 fish km^{-1}) in the streams of the South Slough NERR (Table 4.9). In contrast, Solazzi (2001) observed much higher average densities of 840 migrant fish km^{-1} (95% CI: 320, 1,370 migrant fish km^{-1}) across a range of sites in the Oregon Coast Range. The observations by Solazzi (2001), however, were made only in higher order streams in areas of productive salmonid habitat, and they focused specifically on migrating juveniles.

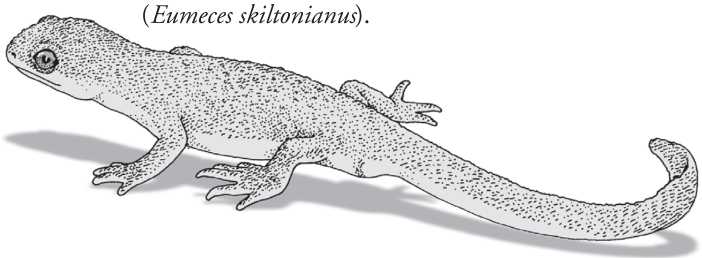
Streams located within the South Slough watershed are inherently limited in their capability to support significant populations of anadromous fish. Salmonids are not commonly associated with geomorphic habitats characterized by low stream gradients and small sediment particle sizes (Scott and Crossman, 1973; Naiman *et al.*, 1992). Slow water glide habitats with sand and silt substrata dominate the streambeds in the South Slough watershed (Stone, 1987). Juvenile coho salmon captured by Denike *et al.*, (1992) in the freshwater streams were most frequently associated with glide habitat and unconsolidated silt and sand streambeds. Salmonids in the South Slough watershed may utilize these sub-optimal habitat types in the absence of graveled riffles and complex pools.

4.2.4.c Riparian Amphibians and Reptiles

Herptiles (amphibians and reptiles) can be the numerically dominant vertebrate group in many riparian and aquatic habitats in the Oregon Coast Range where they provide an essential element of riparian food webs (Corn and Bury, 1991). Twelve of the 16 amphibian species that inhabit Oregon's coastal forests require riparian habitats for foraging and/or reproduction. Riparian areas within the

South Slough NERR support a moderate diversity of herptiles dominated by lentic and pond-breeding species.

Denike *et al.*, (1992) observed at least five species of reptiles and seven species of amphibians during time-constrained surveys of riparian areas located within the South Slough NERR (Tables 4.10, 4.11). Rough-skinned newt (*Taricha granulosa*), red-legged frog (*Rana aurora*) and Dunn's salamander (*Plethodon dunni*) are the most commonly occurring terrestrial / splash zone species in the Reserve. Pacific giant salamander (*Dicamptodon tenebrosus*) and red-legged frogs are the most common amphibians in lotic habitats (Table 4.9). Seven additional species of amphibians have been noted in riparian areas within the Oregon Coast Range physiographic province, including northwestern salamander (*Ambystoma gracile*), clouded salamander (*Aneides ferreus*), tailed frog (*Ascaphus truei*), western toad (*Bufo boreas*), foothill yellow-legged frog (*Rana boylii*), and bullfrog (*Rana catesbiana*). Three additional species of reptiles may also use riparian habitats in the area including snapping turtle (*Chelydra serpentina*), western fence lizard (*Sceloporus occidentalis*) and western skink (*Eumeces skiltonianus*).



Amphibians and reptiles make different use of riparian habitats within the South Slough NERR in comparison to other stream and floodplain areas. Densities of the western red-backed salamander (*Plethodon vehiculum*) and ensatina (*Ensatina eschscholtzii*) in the South Slough are comparable to densities observed in drier geomorphic locations within the Oregon Coast Range (Vesely, 1996; Olson *et al.*, 1999). Densities of southern torrent salamander (*Rhyacotriton variegatus*) and Pacific giant salamander (*D. tenebrosus*) within the Reserve are similar to those described by Vesely (1996), while the local density of Dunn's salamander (*P. dunni*) is similar to densities observed elsewhere (Olson *et al.*, 1999). Local densities of rough-skinned newt (*T. granulosa*) are several orders of magnitude higher than those described by Vesely (1996). High abundance of rough-skinned newts and red-legged frog (*R. aurora*) in the Reserve may be attributable to the large amount of breeding pond habitat and significant spatial extent of wet forested valley floors dominated by red alder (*Alnus rubra*; Table 4.10). Individuals of the tailed frog (*Ascaphus truei*) were noticeably absent from the local surveys. This species is typically associated with cool, clear, fast-flowing streams, and is sensitive to disturbance (Blaustein *et al.*, 1995).

Amphibian communities in the Oregon Coast Range are known to be sensitive to the seral stage and conditions of overstory vegetation (Corn and Bury; 1991; Vesely, 1996). The South Slough NERR supports substantial populations of amphibians in open-canopy habitats (Table 4.10), including high densities of Pacific treefrog (*Pseudacris regilla*), red-legged frog (*R. aurora*) and rough-skinned newt (*T. granulosa*), all of which require lentic habitat for breeding (Figure 4.5). Amphibian species richness is lower in the open-canopied freshwater marsh areas where the Plethodontids are very rare. Conversely, the diversity of reptiles is significantly greater in the open-canopied riparian areas, most likely due to differences in habitat moisture, shade, and temperature (Table 4.10). Members of the South Slough herptile community are distributed in a heterogeneous manner in different positions of the watershed (Table 4.11). Pacific giant salamander, red-legged frog, and rough-skinned newt are common in the lower stream reaches, while Pacific tree frog and rough-skinned newt are common in the middle and upper watershed regions.

Local abundance of salamanders in the riparian woodland areas results in higher amphibian diversity in the closed-canopy forested sites (Table 4.10). Ensatina, torrent salamander, and Dunn's salamander are all associated with closed forest canopies, and these species are absent from the open-canopy habitat types. Intermediate-sized hardwood stands support the greatest densities of amphibians within the forested riparian habitats of the South Slough NERR. Diked pasture grass areas are inhabited by few herptiles, probably because they do not provide a large range of microclimate conditions and they offer limited cover for protection from predators.

In general, riparian areas within the South Slough NERR do not contain unique substrata, and they have limited talus, negligible old growth stands, and low to moderate amounts of downed wood. These conditions, coupled with relatively high levels of historic disturbance, contribute to a local herptile community in the Reserve that is typical of coast range habitats.

Table 4.10. Herptile community within the South Slough NERR, OR. Values indicate no. of reptiles or amphibians captured per 1,000 m^2 (95% C.I.) within different canopy types and cover types of riparian habitats (time-constrained search data from Denike *et al.*, 1992).

		Canopy Type		Cover Type				
	Sample Size ⟶	Open 27	Closed 44	Conifer / Hardwood 31	Hardwood 12	Freshwater Marsh 24	Pasture Grass 3	Total 71
REPTILES								
Charina bottae	Pacific rubber boa	3.7 (-1.6, 9.0)	1.1 (-1.2, 3.4)	1.6 (-1.7, 4.9)	0	4.2 (-1.8, 10.1)	0	2.1 (-0.3, 4.5)
Gerrhonotus coeruleus	Northern alligator lizard	11.1 (1.1, 21.1)	0	0	0	12.5 (1.3, 23.7)	0	4.2 (0.4, 8.1)
Thamnophis spp.	Garter snake spp.	3.7 (-1.6, 9.0)	0	0	0	4.2 (-1.8, 10.1)	0	1.4 (-0.6, 3.4)
Thamnophis ordinoides	Northwester garter snake	9.3 (-0.3, 18.8)	0	0	0	10.4 (-0.3, 21.2)	0	3.5 (-0.1, 7.2)
Thamnophis sirtalis	Common garter snake	5.6 (-0.8, 11.9)	1.1 (-1.2, 3.4)	0	0	6.3 (-0.9, 13.4)	0	2.8 (0.1, 5.6)
Unknown snakes		1.9 (-2.0, 5.7)	0	0	0	2.1 (-2.2, 6.4)	0	0.7 (-0.7, 2.1)
AMPHIBIANS								
Ensatina eschscholtzii	Ensatina	0	2.3 (-0.9, 5.5)	1.6 (-1.7, 4.9)	0	0	0	1.4 (-0.6, 3.4)
Pseudacris regilla	Pacific treefrog	11.1 (-0.3, 22.5)	0	0	0	10.4 (-2.0, 22.8)	16.7 (-55.0, 88.4)	4.2 (-0.1, 8.6)
Plethodon dunni	Dunn's salamander	0	29.5 (15.1, 44.0)	33.9 (15.9, 51.8)	20.8 (-7.8, 49.4)	-	0	18.3 (8.9, 27.7)
Plethodon vehiculum	Western red-backed salamander	1.9	10.2 (-2.0, 5.7)	11.3 (1.2, 19.3)	8.3 (-1.0, 23.6)	2.1 (-4.0, 20.7)	0 (-2.2, 6.4)	7.0 (1.3, 12.8)
Rana aurora	Red-legged frog	53.7 (11.6, 95.8)	17.0 (5.7, 28.4)	16.1 (3.3, 29.0)	16.7 (-11.5, 44.9)	60.4 (13.4, 107.4)	0	31 (13.6, 48.4)
Rhyacotriton variegatus	Southern torrent salamander	0	3.4 (-1.7, 8.5)	4.8 (-2.4, 12.1)	0	0	0	2.1 (-1.0, 5.2)
Taricha granulosa	Rough-skinned newt	55.6 (22.5, 88.6)	33.0 (12.0, 53.9)	17.7 (3.9, 31.6)	75.0 (5.3, 144.7)	54.2 (19.5, 88.8)	66.7) (-220.0, 353.5)	41.5 (23.8, 59.3)
Unknown amphibians		3.7 (-1.6, 9.0)	1.1 (-1.2, 3.4)	0	4.2 (-5.0, 13.3)	4.2 (-1.8, 10.1)	0	2.1 (-0.3, 4.5)
Species Richness		**8**	**9**	**7**	**4**	**8**	**2**	**11**

Table 4.11. Herptiles observed during aquatic surveys within the South Slough NERR, OR. Values indicate mean no. individuals captured (SD) in different watershed positions; sample size is no. of stream reaches (from Denike *et al.*, 1992).

		Watershed position			
		Lower	Middle/Upper	Tributaries	
	Sample Size →	6	9	10	Total
Species	Common Name				
Dicamptodon tenebrosus	Pacific giant salamander	3.4 (6.5)	0 (0)	0 (0)	7.0 (13.0)
Pseudacris regilla	Pacific treefrog	0.2 (0.5)	10.6 (19.3)	5.9 (8.6)	1.0 (2.1)
Plethodun dunni	Dunn's salamander	0 (0)	1.7 (3.0)	0.8 (1.6)	0.1 (0.5)
Rana aurora	Red-legged frog	11.0 (14.8)	0 (0)	0.3 (0.8)	4.7 (8.5)
Taricha granulosa	Rough-skinned newt	2.6 (2.0)	3.8 (5.3)	1.8 (3.2)	1.0 (1.5)
Thamnophis sirtalis	Common garter snake	0 (0)	0.9 (1.2)	0.1 (0.4)	0 (0.2)

Two amphibians found in South Slough NERR are becoming rare in their range. Red-legged frogs (*Rana aurora*) are currently under federal consideration for status as a protected species. In addition, the Oregon Department of Fish and Wildlife sensitive species list also includes red-legged frogs (*R. aurora*) and the southern torrent salamander (*Rhyacotriton variegatus*). Long-term protection and operation of the South Slough NERR as a research / natural area will ensure that critical levels of downed wood and forest stand age will increase within the riparian habitats. However, the moist microhabitat of the valley floors and bottomlands will most likely continue to limit the diversity of herptiles in the Reserve.

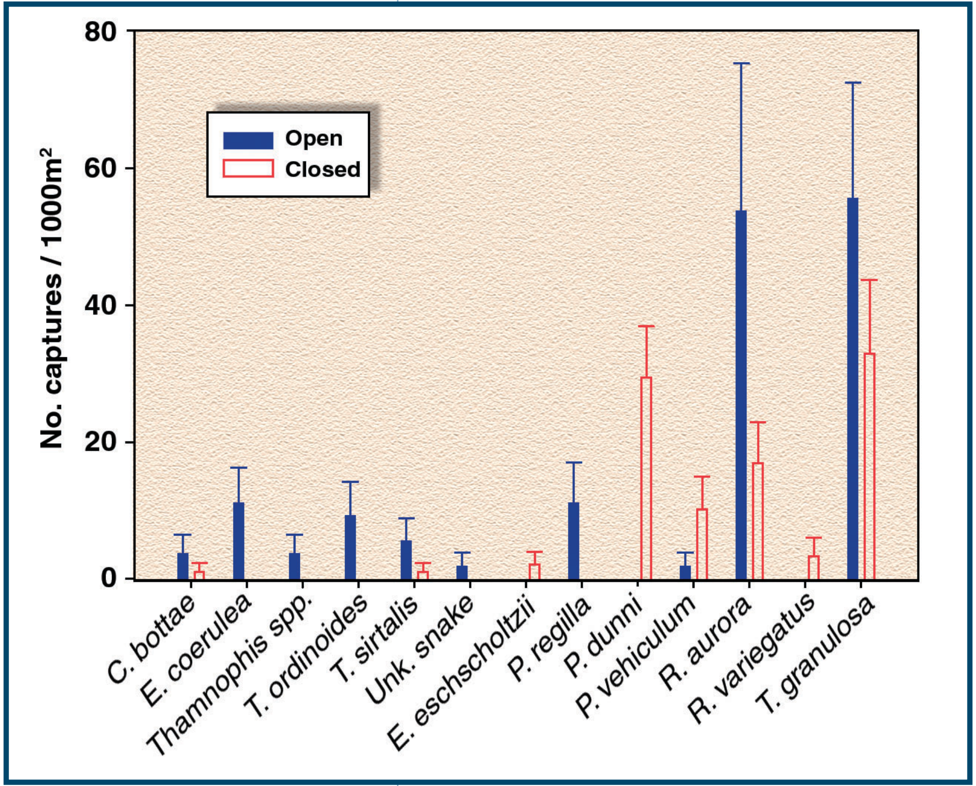


Figure 4.5. Densities of herptiles within open- and closed-canopy riparian habitats (error bars indicate 95% C.I.; time-constrained search data from Denike *et al.*, 1992).

4.2.4.d Bird Communities in Riparian Areas

The birds of riparian areas within the South Slough reflect a strong influence of open-canopy stream reaches, extensive stands of hardwood trees, and the pervasive historic harvests and conversion of forest stands within riparian corridors and adjacent upland areas. Avifauna within the Reserve riparian areas is dominated by species that use habitat edges, seasonal migrants, perching birds, and species adapted to wetlands. A total of 68 bird species were encountered during local surveys of riparian habitats (Denike *et al.*, 1992), although the actual diversity of birds that utilize riparian areas within the Reserve is much higher. Troop-forming birds and species that utilize shrubs are abundant in the riparian zones, including Swainson's thrush, song sparrow, chestnut backed chickadee, bushtit, wrentit and Wilson's warbler. Edge species such as Steller's jay and American crow are also common. However, the opportunistic edge species are not as dominant in riparian systems as might be expected, considering the young age and limited width of most riparian corridors within the Reserve. Winter wren (*Troglodytes troglodytes*) was the only common interior forest bird observed locally in the riparian regions of the South Slough NERR. Western flycatcher (*Empidonax difficilis*) is one of the most common species in the Reserve and one of a few species commonly observed in the middle and upper reaches of streams. The distribution pattern for *E. difficilis* is probably established by utilization of perching habitat in the open understory and ample insect prey afforded by adjacent stands of red alder. Two species of sensitive-status birds (*i.e.,* pileated woodpeckers, *Dryocopus pileatus* and olive-sided flycatchers, *Contopus borealis*) occur at moderate densities in the South Slough NERR. Carey *et al.*, (1991) observed high densities of golden-crowned kinglets, western flycatchers, winter wren, chestnut-backed chickadee, and Wilson's warbler within young and mature upland forest stands in the Oregon Coast Range. All of these species are common in the South Slough NERR riparian areas.

Sheridan (2001) identified 12 guilds of birds within the riparian habitats of the South Slough NERR (Table 4.12). These assemblages are numerically dominated by the thrush-wren guild, sparrows, and the guild of chickadees, bushtits, and wrentits. Members of the cavity-nester guild are relatively abundant in the Reserve riparian areas, particularly considering the low density of snags in riparian and upland habitats (Sheridan 2001). Northern flicker (*Colaptes auratus*) is the most common species in the cavity-nester guild. Members of the duck-wetland bird guild such as the great blue heron (*Ardea herodias*) and Virginia rail (*Rallus limicola*) are commonly observed in lower reaches of the riparian systems. Several species of waterfowl are also included in the duck-wetland guild, and they frequently occur in high densities in middle watershed stream reaches where the spatial extent of pond habitat is frequently high. Nearly all of the bird guilds are more common in the lower stream reaches, and only the flycatchers are more common in the middle and tributary reaches than in lower reaches (Table 4.12).

Table 4.12. Concatenated densities of bird groups in different watershed positions within the South Slough NERR, OR. Values indicate mean no. of observations / riparian habitat plot (SD).

		Watershed position		
		Lower	Middle/upper	Tributaries
Bird Group	**Sample Size ⟶**	**13**	**34**	**39**
Birds of prey		0.1 (0.3)	0.1 (0.2)	0.1 (0.2)
Cavity nesters		0.6 (0.7)	0.4 (0.8)	0.3 (0.6)
Chickadees/Bushtits/Wrentits		2.2 (2.8)	1.1 (1.9)	1.2 (1.6)
Ducks/wetland birds		0.5 (1.1)	0.4 (1.1)	0 (0)
Flycatchers		0.5 (0.7)	1.1 (0.9)	1.1 (0.9)
Finches/Blackbirds		0.2 (0.4)	0.1 (0.3)	0.2 (0.5)
Jays/Crows		1.2 (1.4)	0.9 (1.0)	0.9 (1.9)
Other		0.6 (0.8)	0.7 (1.3)	0.7 (1.0)
Sparrows		2.2 (1.2)	1.0 (1.5)	0.8 (1.4)
Swallows		0.8 (1.5)	0.4 (1.0)	0.3 (1.2)
Thrushes/Wrens		3.4 (1.1)	2.8 (1.9)	2.4 (1.6)
Vireos/Warblers		0.5 (0.9)	1.1 (1.6)	1.0 (1.2)

4.2.5 Ecological Role of Riparian Corridors

Riparian zones serve numerous ecological roles that are integral to the functioning of both aquatic and terrestrial habitats in the Pacific northwest region (Naiman *et al.*, 1992). Ecological processes within the riparian areas of the South Slough NERR are structured by interactions between the wet maritime climate, rugged geomorphology, and frequent disturbance regime. As dynamic ecotone habitats, the riparian zones function to channel and mediate fluxes of water, air, inorganic and organic matter, and organisms within the coastal landscape of the South Slough watershed.

The wet maritime climate and sedimentary geology (including uplifted sandstone and stabilized sand dune landforms) of the South Slough watershed are the ultimate drivers of riparian functions in the South Slough NERR. These driving forces are confounded by hillslope disturbance processes (including soil movement and windthrow), fluvial disturbances (including hydrological regime, moisture gradients, winter freshets, and summer droughts), flooding and saturation levels, tidal action, and the dam-building activities of beavers. The resulting geomorphology of riparian habitats includes both: (a) unconstrained drowned river valleys and floodplains in the lower reaches of the South Slough watershed, and (b) constrained, dissected riparian habitats in the steeper hillslopes. This dichotomous geomorphic diversity provides sharp gradients in microclimates across riparian corridors. Riparian habitats within the South Slough NERR provide a linear branching spatial pattern of cool, shaded microhabitats situated within the context of the warmer and younger upland areas (Figure 4.1). Riparian habitats within the Reserve also serve as avenues to transport dissolved and particulate nutrients and sediment downstream to the estuarine tidal basin.

Riparian zones perform functions that are important to maintenance of salmonid metapopulations along the southern Oregon coast, and they are integral to the support of recovering salmonid populations in the South Slough watershed. The South Slough estuary provides rich foraging environments for juvenile salmonids and a strong salinity gradient for smoltification (Frank *et al.*, 1990). In addition, freshwater stream habitats provide spawning habitats and overwintering areas for juvenile salmonids, and they can act as refugia from predators. In a reciprocal fashion, returning salmon provide nutrients and support to riparian food chains across multiple trophic levels, from large mammals (*e.g.,* black bear) to invertebrates (e.g., black fly larvae, Johnson and O'Neil, 2000). Production capacity for salmonids within the South Slough watershed is relatively low in comparison with the larger fluvial systems that feed the adjacent Coos and Coquille estuaries. The South Slough watershed, however, may provide spatially separated, low-disturbance refugia for populations of coho salmon and cutthroat trout. Riparian habitats within the South Slough NERR also provide a source of water and essential ecological support for numerous vegetative communities and other species groups including aquatic insects, amphibians, reptiles, birds, and mammals. The cooler microhabitats provided by riparian corridors constitute a shaded canopy cover that facilitates movement through younger upland habitats.

Riparian zones in the Pacific northwest region are structured by a host of fluvial and upland disturbances that vary across temporal and spatial scales, producing greater structural and compositional diversity than the more homogenous adjacent upland landscapes (Gregory *et al.*, 1991; Naiman *et al.*, 1992). Riparian habitats located within the South Slough NERR are currently recovering from a disturbance regime that is unique within the South Slough watershed and the surrounding coastal landscape. After a century of intensive timber harvests, livestock grazing, and frequent removal of overstory vegetation, the existing riparian habitats and surrounding uplands within the Reserve will be disturbed by active remedial activities and by natural fluvial and geomorphic processes for the foreseeable future. This change in disturbance regime will greatly affect the development of in-stream habitat structure, diversity of microclimates, and the composition of plant and animal communities. Although the majority of riparian habitats are of similar age due to widespread timber harvests and overstory removal throughout the past century, processes of ecological succession may follow dissimilar pathways in the distinct riparian systems due to local differences in geomorphology, disturbance stochasticity, and in the pivotal ecological role of salmonberry (*Rubus spectabilis*) following the maturation and senescence of red alder stands (*Alnus rubra*). These processes will lead to localized divergence in the physical structure and species composition of floral and faunal assemblages in the riparian zones of the South Slough.

4.3 Upland Forest Habitats and Communities

Upland regions of the South Slough NERR include coastal landforms that are dominated by stabilized sand dunes and uplifted marine terraces. The rolling hills and steep valleys of the South Slough watershed transition directly into the foothills of the Oregon Coast Range. Annual precipitation averages over 150 cm within the South Slough watershed, and increases to over 250 cm yr^{-1} in the steep ridges of the nearby Elliott State Forest. Precipitation occurs primarily as rain during the stormy season (November-March), but the upland habitats also receive substantial moisture as fog drip during summer months. Temperatures are generally moderate, with less than 30° C difference between summer and winter maxima (see Figure 1.8).

South Slough NERR is situated within the Sitka spruce (*Picea sitchensis*) zone, a variant of the western hemlock (*Tsuga heterophylla*) coastal forest (Franklin and Dyrness, 1973; Schultz, 1990). The Sitka spruce zone is characterized by frequent summer fog and close proximity to the ocean, and the associated upland plant communities reflect the nutrient-poor, well-drained soils, high winter precipitation, and direct influence of the maritime climate. Upland forest communities within the South Slough NERR are dominated by mesic coniferous forests with scattered brushy areas. Hillslopes within the upland habitats average 18.4 % (SE = 3.1), with maximum continuous slopes of 57% (and greater over short sections in the headwall areas). Exposure aspects are highly variable within the Reserve, and most hillsides face east or west toward the South Slough estuary or a concave drainage basin. All upland regions of the South Slough NERR are within 10 km of the Pacific Ocean, and at most 5 km from an arm of the South Slough estuary. Elevations of these upland habitat areas range from 3 m to almost 125 m above sea level.

4.3.1 South Slough Site History: The Role of Fire and Harvest Management

Human activities, including fire suppression, logging and road installation have significantly altered the historical disturbance regime in the Oregon Coast Range over the last 150 years. Coastal temperate rainforests like those in the South Slough watershed have adapted to the occurrence of both: (a) infrequent, severe, stand-replacement fires, and (b) more frequent, low to moderately severe fires of native American origin (Agee, 1993). Disturbance patterns created by these pyric processes may be necessary to maintain the long-term stability of plant and animal communities present in these coastal systems (Sando, 1978).

4.3.1.a History and Role of Fire

Limited information exists regarding the specific fire history of the South Slough watershed. Native Americans including the Miluk Indians probably underburned the marshes and river fringe areas frequently (*i.e.,* return interval less than 50 years). Extensive forest fires that originated from the activities of European settlers were noted in the Coos Bay area from 1849 to 1902 (Morris, 1934). A great fire burned large portions of the South Slough in 1874, and the Bandon fire of 1936 burned much of the southern portion of the Reserve, the South Slough watershed, and the adjacent coastal landscape. Extensive, stand-replacing fires have been excluded from the South Slough NERR since at least the 1950's, although grazing of the upland areas (by cattle and sheep) involved frequent broadcast burning (Laport, 2002).

4.3.1.b History of Land Use

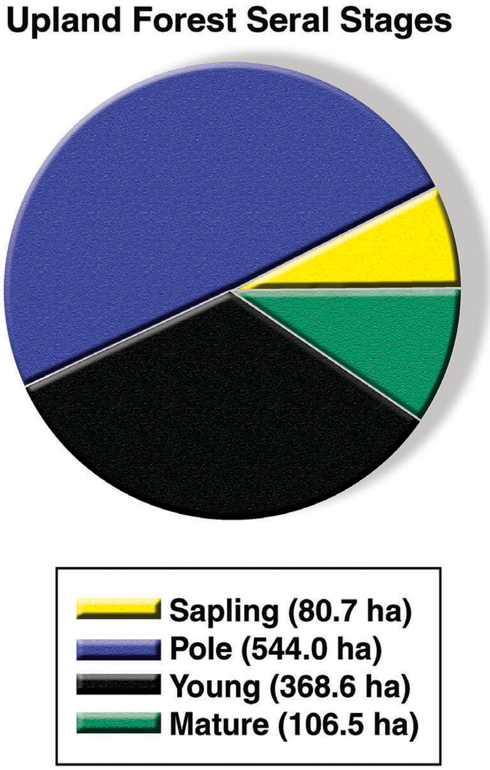
Land use and forest management practices have probably played a more significant role in shaping the structure of existing upland communities in the South Slough watershed than fire over the last 100 years. The majority of upland areas within the South Slough NERR have experienced significant historical grazing and overstory removal within the last century (Carey 1990). The South Slough watershed was one of the first areas logged after settlement of the Coos Bay area in the early 1850's. Extensive railroad logging was conducted shortly after the turn of the century, and large industrial operations (principally Georgia Pacific Co.) conducted intensive logging activities throughout the watershed after the end of World War II. By 1954, second-growth timber on the east side of the South Slough estuary had been cut, and much of the Winchester Creek sub-basin was logged between 1954 and 1962. In the 1950s many open areas were planted back with Douglas-fir (Laport, 2002). At least 15 separate areas were clear-cut within the South Slough watershed during the past 35 years, and at least eight of these are located within the current administrative boundaries of the South Slough NERR (SSNES, 1984).

Installation of permanent (blacktop) roads has not been prevalent in the South Slough watershed, and they are virtually absent from the South Slough NERR. As such, the Reserve lands represent a significant contiguous block of upland coastal forest within the South Slough coastal watershed and drainage basin. Sheridan (2001) estimated that 79.1% (SE 3.0%) of the Reserve lands had the potential for development of interior forest stand characteristics, assuming continued absence of significant human and natural disturbances. Upland areas contain a myriad of abandoned roads and bulldozer trails in excess of 2 km km^2 (Sheridan 2001) that were constructed prior to designation of the South Slough NERR. In the absence of active maintenance, the vast majority of these abandoned roadways will be reclaimed by the process of forest succession. Only one gravel road is maintained to provide access to the interior forest region of the Reserve. The effects of road building, overstory removal, and interruption of the historic fire regime will not be directly addressed by the present summary, although these factors can strongly influence the composition of biotic communities.

4.3.2 Upland Forest Overstory Communities

Upland overstory communities within the South Slough NERR are currently composed primarily of early and mid-seral conifer forests. Over 60% of the Reserve upland areas are covered by coniferous forests (Figure 4.6). Mixed conifer / hardwood forest types cover 16% of the upland areas, while conifer / brush and exclusive brush field forest types together cover another 16% of the Reserve. Hardwood forest constitutes only 2% of the upland overstory within South Slough NERR.

Upland forests within the South Slough NERR can be categorized as either: (a) sapling (0-20 yrs old), (b) pole (21-40 yrs), (c) young (41-80 yrs), or (d) mature (>80 yrs old) forest stages. Forested upland areas in the Reserve are primarily in the pole (49%) and young (34%) seral stages of stand development (Figure 4.6, Table 4.13). Approximately 80 ha (<1%) of the forested habitats within the South Slough NERR are currently in the sapling stage, and about 10% of the upland areas of the Reserve are currently categorized as mature forest.



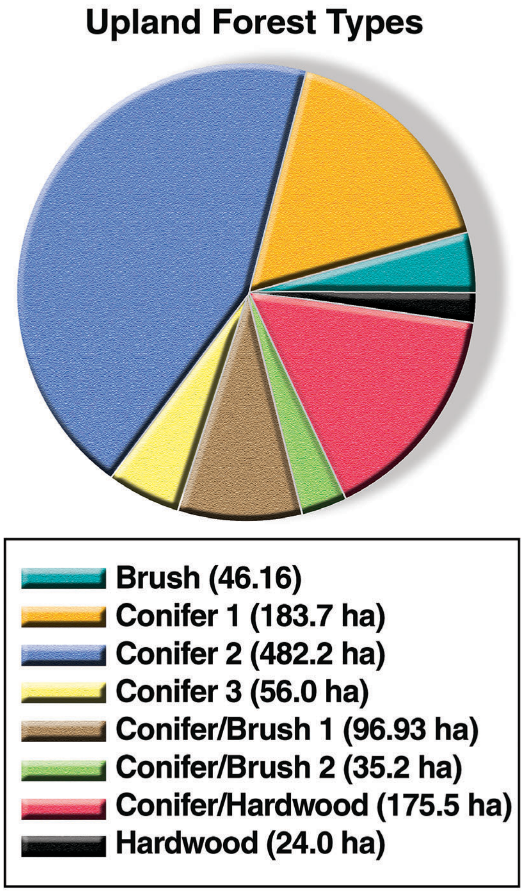


Figure 4.6. Seral stages and forest community types in upland forest habitats within the South Slough NERR, OR. Height classes for coniferous trees are 1: 0-10m, 2: 10-20m, 3: >20m (from field surveys conducted in1993).

Table 4.13. Basal area (BA) measurements for coniferous and deciduous tree communities within different forest seral stages in the South Slough NERR, OR. Values indicate tree basal area in m^2/ha (95% C.I.) from surveys conducted in 1993.

	Forest Seral Stage				
Common Name ***(Scientific name)***	**Sapling BA** ***(n=6)***	**Pole BA** ***(n=37)***	**Young BA** ***(n=36)***	**Mature BA** ***(n=6)***	***Total***
Red alder	0	2.9	28.3	3.3	13.9
(*Alnus rubra*)		(-1.9, 7.6)	(7.8, 48.8)	(-5.2, 11.9)	(4.5, 23.3)
Port-Orford-cedar	55.0	51.8	20.6	13.3	35.4
(*Chamaecyparis lawsoniana*)	(24.5, 85.5)	(35.4, 68.2)	(8.6, 32.7)	(-12.1, 38.8)	(25.9, 45.0)
Sitka spruce		18.3	35.9	3.3	23.9
(*Picea sitchensis*)		(5.9, 30.7)	(19.8, 52.1)	(-5.2, 11.9)	(14.9, 33.0)
Douglas-fir	5.0	38.0	31.9	3.3	31.1
(*Pseudotsuga menziesii*)	(-10.9, 20.9)	(19.3, 56.6)	(12.7, 51.1)	(-5.2, 11.9)	(19.4, 42.7)
Cascara buckthorn	0	3.4	2.9		2.8
(*Rhamnus purshiana*)		(-0.8, 7.7)	(-0.5, 6.3)		(0.4, 5.1)
Western redcedar	0	0	2.3	50.0	4.8
(*Thuja plicata*)			(-2.4, 6.9)	(-28.3, 128.3)	(-0.7, 10.2)
Western hemlock	25.0	45.7	43.3	83.3	46.4
(*Tsuga heterophylla*)	(-54.6, 104.6)	(23.3, 68.1)	(23.6, 63.0)	(13.8, 152.8)	(32.8, 60.1)

Some mature areas contain several structural components of a coastal old growth forest, although no entirely unmanaged old growth forests occur within the upland areas of the South Slough NERR.

Upland forests in the South Slough NERR are currently dominated by 30-80 year old stands. This age group is consistent with the prior history of timber harvests and land management within the South Slough watershed. Removal of standing trees has been prohibited within the administrative boundaries of the South Slough NERR since 1974. Predominance of early to mid-seral stage forest stands has an important influence on the composition of overstory vegetation, size and density of overstory trees, and the characteristics of forest legacy components (*i.e.,* residual overstory trees, snags, and downed wood). Species composition of overstory vegetation communities is highly variable within the Reserve, and the structural characteristics of the upland forests differ substantially at the scale of individual forest management areas (MAs). Much of the descriptive information collected within the South Slough NERR by Sheridan (2001) exhibits high intrinsic variability at the scale of forest MAs, and should be considered as representative of the range of variation in upland characteristics rather than precise stand averages.

4.3.2.a Composition of Overstory Communities

Overstory communities in the South Slough NERR include seven primary species of trees: red alder (*Alnus rubra*), Port-Orford-cedar (*Chamaecyparis lawsoniana*), Sitka spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*), cascara buckthorn (*Rhamnus purshiana*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*; Table 4.13). Several other species of trees, including grand fir (*Abies grandis*), big-leaf maple (*Acer macrophyllum*), shore pine (*Pinus contorta*), Oregon myrtle (*Umbellularia californica*), madrone (*Arbutus menziesii*), chinquapin (*Castanopsis chrysophylla*), western crabapple (*Pyrus fusca*), bitter cherry (*Prunus virginiana*), and willow (*Salix* spp.) occur at low densities in upland areas of the Reserve, but they did not occur in the forested MAs surveyed by Sheridan (2001).

Upand forest areas within the South Slough NERR support a moderately elevated diversity of overstory vegetation in comparison to more intensively-managed forest landscapes surrounding the Reserve that are dominated primarily by commercial stands of Douglas-fir. Shade-tolerant conifers, including western hemlock and Port-Orford-cedar, are currently co-dominants along with Douglas-fir in

Table 4.14. Summary characteristics for site productivity of upland forest communities within the South Slough NERR, OR. Values indicate means (95% C.I.). Sample size varies by metric and is the smallest sample size for each forest seral stage.

	Forest Seral Stage				
	Sapling	Pole	Young	Mature	
Sample size ⟶	1	17	12	3	Total
Site class	1	2.9 (2.3, 3.48)	2.5 (1.5, 3.5)	3 (-1.3, 7.3)	2.7 (2.2, 3.2)
Radial growth 5 yr mm		11.7 (7.4, 16.0)	11.8 (6.7, 16.8)		12.2 (9.1, 15.4)
Radial growth 10 yr mm		26.5 (17.0, 36.1)	25.9 (16.0, 35.9)		27.2 (20.7, 33.8)
Crown ratio %	67.2 (35.7, 98.6)	32.8 (26.1, 39.5)	31.8 (28.1, 35.5)	16.0 (7.2, 24.7)	32.9 (28.8, 37.1)
Height / Diameter ratio	66.4 (48.5, 84.4)	67.6 (58.9, 76.2)	67.0 (53.6, 80.9)		67.3 (60.2, 74.4)
Regeneration # stems / ha	957.5 (-209.5, 2124.5)	1379.6 (458.8, 1379.6)	180.2 (-505.8, 866.2)	446.8 (-373, 1267.3)	567.2 (340.7, 793.7)

the upland forested areas (Table 4.13). By comparison, information from historic timber cruises indicates that Sitka spruce, Douglas-fir, hemlock, and Port-Orford-cedar were the most abundant trees in the southern portion of the South Slough in 1909 (Carey, 1990). Red alder is the only hardwood species to achieve significant aerial cover in the Reserve. Seral succession in the *Picea sitchensis* zone typically involves replacement of mixed coniferous forests by *Tsuga heterophylla* (Franklin and Dyrness, 1973). In the South Slough NERR management areas, the basal area of Port-Orford-cedar, Sitka spruce and Douglas-fir decreases in more mature sites while the basal area of western hemlock increases with forest stand age (Table 4.13).

4.3.2.b Forest Site Productivity, Density and Size Structure

Size and density characteristics of the upland overstory community are determined primarily by successional dynamics in the mid seral pole and young management areas that dominate the South Slough NERR (Table 4.14). The site class of dominant trees averages 2.7 within the South Slough. By comparison, forests in similar associations located within the nearby Siuslaw National Forest have an average site class of 2 (Hemstrom and Logan, 1986). Productivity in both areas is affected by summer drought, low nutrient status and relatively low soil pH. The size of trees (measured as Diameter at Breast Height; DBH), tree density (# trees ha^{-1}), and radial growth rate averages for forests within the South Slough NERR management areas are comparable to the values for un-thinned young seral stands described by Tappeiner *et al.*, (1997) for other locations in coastal Oregon. Basal area values are nearly identical for the mature, young, and pole stage forest stands and average 36.6 m^2 ha^{-1} (Figure 4.7, Table 4.15). These basal area values for the South Slough NERR forests, however, are lower than values for the young stands described by Tappeiner *et al.*, (1997). Lower tree cover in the South Slough NERR may be attributable to the low site class and historically poor replanting success in the Reserve.

Estimates of Relative Density (RD) can be derived from direct field measurements of tree basal area and the quadratic mean diameter-at-breast height to yield a single metric for comparing tree densities among different management areas (Curtis 1982). Relative density values in excess of 15 imply the onset of forest canopy crown closure, while RD values >50 imply the onset of tree mortality from competition with other trees for limited light and space. The dense pole and young seral stage forest management areas that dominate upland habitats within the South Slough NERR have high RD values

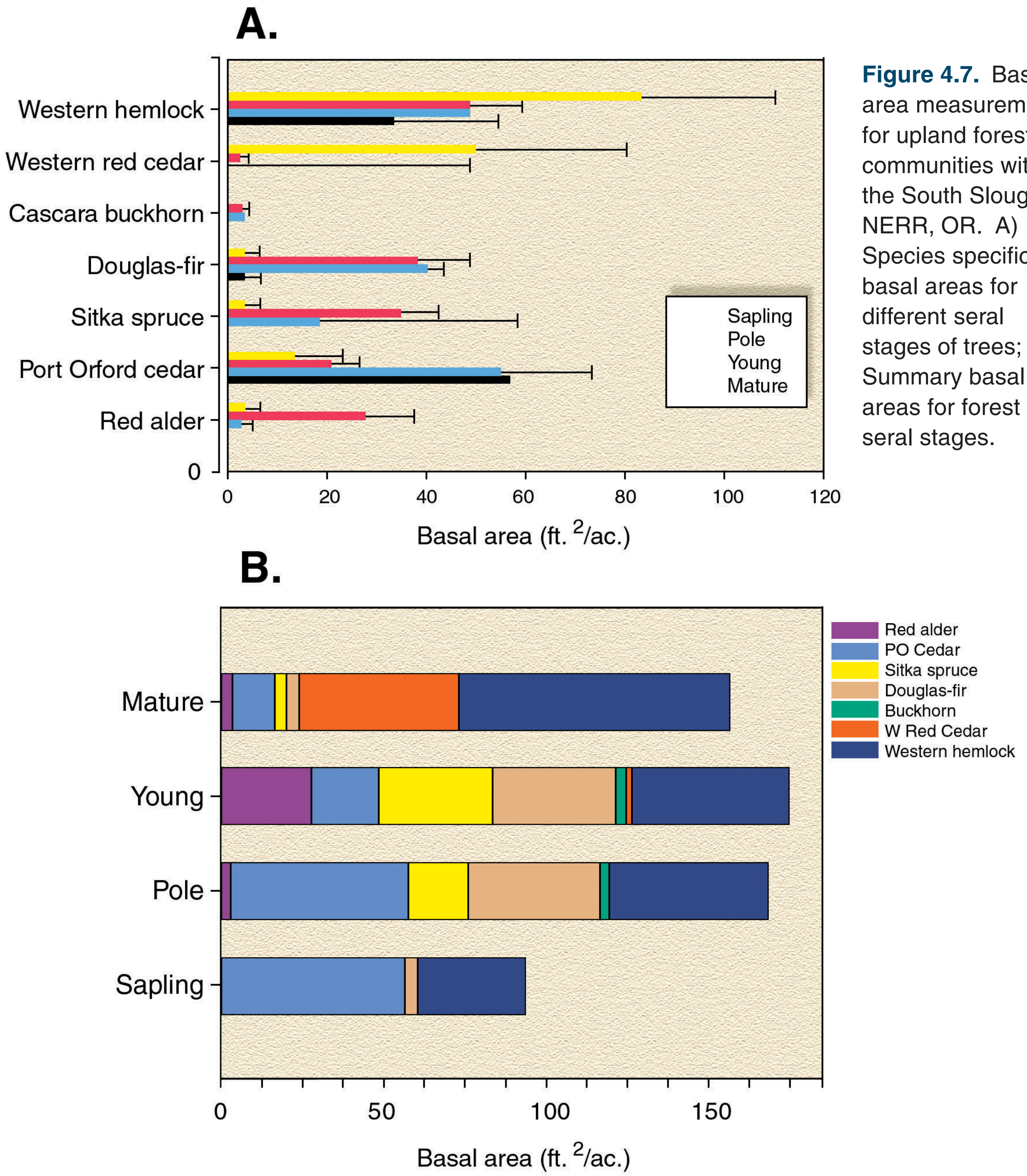


Figure 4.7. Basal area measurements for upland forest communities within the South Slough NERR, OR. A) Species specific basal areas for different seral stages of trees; B) Summary basal areas for forest seral stages.

that indicate the onset of competition mortality (Table 4.15). Tree radial growth rates, crown ratios, and height-diameter ratios also suggest the onset of stem exclusion within the pole and young management areas (Table 4.14). Similarly, sapling areas have RD values that are consistent with crown closure, and the oldest mature forest areas within the South Slough NERR appear to have undergone suppression mortality and entered the process of understory reinitiation.

4.3.2.c Upland Forest Canopy

Complexity of the forest canopy develops during the understory reinitiation phase of forest succession and is characterized by an increase in the abundance of overtopped shade-tolerant trees, shade-tolerant saplings, and residual overstory trees (USFS, 1994). In the South Slough NERR, overtopped trees account for only a negligible portion of the total basal area in sapling areas, almost 10% of the basal area in pole and young stage areas, and over 13% in mature forest stands. Increased density of overtopped trees probably represents temporal progression from the stand establishment phase to the understory reinitiation phase of forest development (USFS, 1994).

Residual overstory trees originate prior to the last significant harvest disturbance and are usually significantly older than the median age of trees in a stand. These residual overstory (legacy) trees provide valuable vertical structure and mature forest habitat for the support of wildlife diversity (Johnson and O'Neil, 2000). Spatial coverage by residual overstory trees is about 1% for the sapling areas of the South Slough NERR, and the area occupied by these legacy trees is much higher in the older forest management areas (Sheridan 2001). Residual overstory trees may have been intentionally retained as seed sources during commercial harvests, or they may be remnants of earlier cohorts established in brushy conditions. By comparison, large residual Douglas-fir trees make up <1% of the total tree density in young forest stands and approximately 4% of total tree density in old-growth stands in naturally regenerating Douglas-fir forests in Oregon (Spies and Franklin, 1991).

Regeneration by understory seedlings and sapling trees is elevated and highly variable in most of the forest seral stages within the South Slough NERR. Sapling and pole-stage areas currently have average regeneration levels of over 950 stems ha^{-1} (Table 4.14). In contrast, young forest management areas had the lowest numbers of regenerating seedlings (180 stems ha^{-1}), and mature management areas exhibited an intermediate regeneration level (447 stems ha^{-1}). Regeneration levels observed for young and mature areas within the South Slough NERR are consistent with values collected in the Douglas-fir zone of the Oregon Cascades (Spies and Franklin, 1991), and with transition from the stem exclusion phase to the understory reinitiation phase of forest stand development (USFS, 1994). Port-Orford-cedar accounts for 20% (95% CI: -52, 92) of all regenerating seedlings and saplings in the Reserve, and western hemlock averages 11% (95% CI: -45, 67%) of all seedlings. Regeneration levels for cascara buckthorn, western redcedar and other trees occur at lower densities. Strong recruitment of Port-Orford-cedar and western hemlock observed in sapling stands is roughly comparable to understory development in Port-Orford-cedar / evergreen huckleberry associations in the Oregon Dunes National Recreation Area (Christy *et al.*, 1998).

4.3.2.d Succession of Forest Seral Stages

Pole and young-stage forest management areas currently comprise 83% of the upland forest habitats in the South Slough NERR. Consequently, the structure and composition of pole and young forest management areas contribute substantially to the overall dynamics of upland forests within the Reserve at the landscape level.

Table 4.15. Summary characteristics for forest size and density of upland forest communities within the South Slough NERR, OR. Values indicate means (95% C.I.).

	Forest Seral Stage				
	Sapling	Pole	Young	Mature	
Sample size →	6	37	36	6	Total
Canopy cover	47.3	83.2	87.4	86.8	82.8
%	(-16.4, 110.9)	(73.6, 92.9)	(79.4, 95.5)	(73.6, 100.1)	(76.6, 89.1)
Density	1374.7	1302.8	708.9	199.8	961.5
trees / ha	(-6.0, 2755.3)	(948.8, 1656.9)	(465.9, 951.8)	(85.4, 314.2)	(756.9, 1166.0)
Dia. Breast Ht.	17.9	27.3	46.0	68.8	38.2
cm	(10.7, 25.0)	(22.8, 31.7)	(37.0, 55.0)	(46.4, 91.1)	(32.8, 43.6)
Basal Area	19.5	36.7	39.0	34.0	36.8
m^2/ ha	(-4.6, 43.6)	(27.7, 45.8)	(31.3, 46.7)	(18.3, 53.6)	(31.5, 42.0)
Relative Density	32.0	48.9	45.3	28.3	44.6
%	(-7.8, 71.8)	(36.2, 61.6)	(35.5, 55.1)	(15.0, 41.6)	(37.6, 51.6)
Height[a]	11.3	15.4	23.9		18.9
m	(9.8, 12.7)	(13.1, 17.6)	(18.4, 29.5)		(16.1, 21.9)

[a] - Height measurements are inherently biased because they are based on site trees rather than average conditions.

Table 4.16. Spatial cover estimates for herb and shrub communities within different forest seral stages in the South Slough NERR, OR. Values indicate mean % cover (SE).

Cover Type	Sapling	Pole	Young	Mature	Total
Herbaceous plants	4.8	6.6	26.0	1.8	14.7
	(2.2)	(2.4)	(6.2)	(1.4)	(3.1)
Shrubs	85.8	64.4	63.1	98.8	66.6
	(32.1)	(7.5)	(7.3)	(10.1)	(5.4)
Total Cover	89.5	71.4	89.2	100.5	
	(36.4)	(8.3)	(5.9)	(8.9)	

Upland habitats within the South Slough NERR currently appear as densely-stocked young forests with patchy areas of less dense trees. Species richness and structural diversity of these dense pole and young seral forest stages are low, and a strong regeneration layer is currently under development.

With passive management of the upland forest areas of the South Slough NERR, stand succession in the young dense forest stands will probably follow a trajectory roughly similar to that described for naturally regenerating forest stands (USFS 1994). Upland forest areas that are currently in the stem exclusion and understory reinitiation phases should eventually achieve shifting gap and old-growth conditions. The successional trajectory to mature stands could take several decades, however, and the transition toward the shifting gap phase in these unmanaged areas could take 100 to 500 years. Tree densities in the pole and young-stage management areas in the South Slough NERR are significantly elevated in comparison to naturally regenerating areas (Tables 4.14 and 4.15; Tappeiner *et al.*, 1997). High densities of trees in these areas may significantly affect both the rate of successional change and the ability of the existing forest stands to reach a shifting gap seral condition. The temporal trajectory of forest stand succession may be further interrupted by the spread of exotic species. For example, Port-Orford-cedar root rot (*Phytophthera lateralis*) is an introduced pathogen that kills cedar trees throughout the watershed. Dense forest stands (with RD values >50) often have greatly reduced crown ratios and cannot develop the photosynthetic resources necessary for development of the massive size and height characteristics of old-growth trees (Spies and Franklin, 1991). It is impossible with current knowledge to quantify the degree to which this condition exists in the upland forest management areas of the South Slough NERR, but many forested areas of the Reserve will probably be retarded in their successional development without direct management and density intervention.

4.3.3 Upland Shrubs and Herbaceous Vegetation

Upland forest floors within the South Slough NERR exhibit relatively little habitat heterogeneity, and they are generally characterized by dense covers of mesic shrubs and limited cover of herbaceous plants (Table 4.16). Species richness of shrubs and herbaceous vegetation averaged 8.2 species (95% CI: 0.7, 15.7 species) within the upland forest management areas, and the Shannon Diversity Index averaged 1.27 (95% CI: 0.3, 2.2). Only 39 species of shrubs and herbaceous plants were identified within all forest age classes, including 17 shrubs and 22 herbaceous plants. The diversity of shrubs and herbs in the South Slough NERR is about 20% of the values reported previously for naturally regenerating stands of Douglas-fir in the Oregon Coast Range (Spies and Franklin, 1991). Species richness of shrubs and herbs in the South Slough NERR, however, is similar to the diversity observed for the Port-Orford-cedar / evergreen huckleberry (CHLA/VAOV) association in the Oregon Dunes National Recreation Area (Christy *et al.*, 1998). Low beta diversity observed by Sheridan (2001) in South Slough upland forest management areas may be a result of mesic conditions and poor soils, and/or an artifact of small sample size.

4.3.3.a Shrub Communities

Dense mesic shrubs dominate the forest floors of upland habitats in the South Slough NERR (Table 4.16). Upland management areas in the Reserve averaged 66.6% cover by shrubs compared with 14.7% cover by herbaceous plants. Salal (*Gaultheria shallon*) and evergreen huckleberry (*Vaccinium ovatum*) are the principal species of shrubs that dominate the

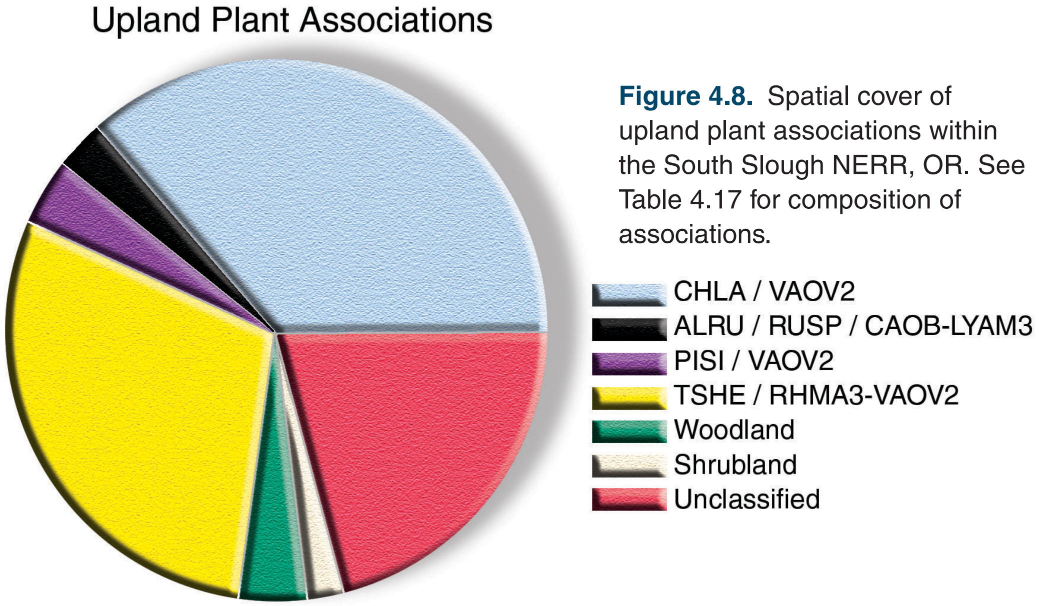


Figure 4.8. Spatial cover of upland plant associations within the South Slough NERR, OR. See Table 4.17 for composition of associations.

forest floor. Evergreen huckleberry exhibited the greatest spatial cover values (mean 20%-70% cover) in the different forest seral stages, and occurred at a frequency of over 75% in all but the pole stage forest management areas. Salal was the single most abundant shrub in the Reserve with a frequency of over 70% in all forest stages. Red huckleberry, sweet gale (*Myrica californica*) and western rhododendron (*Rhododendron macrophyllum*) are also abundant within most of the upland forests of the South Slough NERR.

Spatial coverage by shrubs differs slightly with forest successional stage (Table 4.16). Evergreen huckleberry, red huckleberry (*Vaccinium parviflorum*), salal, cascara buckthorn (*Rhamnus purshiana*), rhododendron and sweet gale (*Myrica californica*) have high spatial cover values in sapling areas. Evergreen huckleberry, red huckleberry, salmonberry (*Rubus spectabilis*) and salal dominate the pole and mature forest stages. Evergreen huckleberry has the highest cover in mature stands, along with rhododendron, sweet gale, salmonberry, elderberry (*Sambucus racemosa*), and red huckleberry.

4.3.3.b Communities of Herbaceous Plants

Spatial coverage by herbaceous plants is generally low within the upland forests of the South Slough NERR (Table 4.16). These low cover values for herbs are similar in magnitude to those described by Spies and Franklin (1991) for other naturally-regenerating Douglas-fir forests in Oregon. Larger forbs, principally sword fern (*Polystichum munitum*), deer fern (*Blechnum spicants*) and bracken fern (*Pteridium aquilinum*), are the most frequently occurring herbaceous plants in the Reserve (Sheridan 2001). Sword fern, deer fern and bracken fern, along with Siberian candyflower (*Claytonia siberica*), bedstraw (*Galium* spp.), and clubmoss (*Lycopodium* spp.) are the only species to average more than 1% spatial cover in any seral stage. Herb coverage is significantly higher in the young forest seral stage (Table 4.16). Hardwood communities support higher herb coverage than other forest types, and older conifer areas have much lower spatial coverage by both herbs and shrubs (Sheridan 2001). Certain species, including slough sedge (*Carex obnupta*), pearly everlasting (*Anaphilis margaritacea*), club moss and redwood sorrel (*Oxalis oregana*), are more common in early seral areas. Sword fern appears most frequently in pole and young stands.

4.3.4 Vegetation Associations in Upland Habitats

Vegetation communities in the South Slough NERR are dominated by species that are adapted to the wet maritime climate and well-drained loamy soils. Forest management areas in the Reserve can be generally described as members of the *Tsuga heterophylla-Picea sitchensis / Gaultheria shallon / Blechnum spicant* community type (Franklin and Dyrness, 1973). However, *B. spicant and Acer circinatum* (vine maple) are far less common in the South Slough NERR compared to the typical community. Sheridan (2001) categorized assemblages of upland plants in the South Slough NERR with plant association keys developed for the Oregon Dunes National Resource Area (Christy *et al*., 1998). The two plant associations identified within the South Slough NERR that exhibit high spatial coverage are the Port-Orford-cedar / evergreen huckleberry (CHLA/VAOV2) association, and the western hemlock / western rhododendron - evergreen huckleberry (TSHE/RHMA-VAOV) association (Figure 4.8, Table 4.17).

The CHLA/VAOV2 association is the most prevalent assemblage of upland plants in the South Slough NERR where it makes up 401 ha of distinctive upland habitat (Table 4.17). This association is unique to the stabilized sand and historic marine terraces that make up the South Slough watershed, and the species composition of the CHLA/VAOV2 assemblage is distinctly different from forest communities that grow on soils derived from other sedimentary or basaltic parent material (Price, pers. comm.). Port-Orford-cedar, Douglas-fir and Sitka spruce dominate the coastal forest stands within the Oregon Dunes National Recreation Area, while evergreen huckleberry dominates the shrub layers. Herb cover is typically minimal, dominated by bracken fern and sword fern. The TSHE/RHMA-VAOV association described for the Oregon Dunes National Recreation Area occurs on the leeward side of stabilized dunes, where the sandy habitats have been protected from salt spray. Herb cover is usually sparse, and the moderately dense forest canopy of this association is dominated by western hemlock, with or without Douglas-fir. Evergreen huckleberry, western rhododendron, and salal dominate the shrub layers where total shrub cover ranges from 25-95%.

Although the upland forest management areas within the South Slough NERR can be assigned to separate and distinct vegetation associations, the dominant upland community within the Reserve contains species assemblages and characteristics of both the CHLA/VAOV2 and TSHE/RHMA-VAOV associations. Overstory communities within the Reserve include high densities of both western hemlock and Port-Orford-cedar, while the understory trees are principally Port-Orford-cedar, western hemlock, and cascara buckthorn. Shrub layers in the South Slough NERR are typically composed of evergreen huckleberry and salal, similar to both the CHLA/VAOV2 and TSHE/RHMA-VAOV associations. Unlike these associations, upland forest communities within the Reserve also support relatively high numbers of Sitka spruce but do not contain significant numbers of shore pines. Biotic diversity of the native plant communities within the South Slough NERR is threatened by the

Table 4.17. Forest size and density characteristics for upland plant associations identified within the South Slough NERR, OR. Values indicate means (SD).

Association	*n*	Total area (ha)	DBH (cm)	Basal Area (m^2/ha)	TPH (# trees / ha)
CHLA/VAOV2	13	400.8	33.1	46.4	1223.8
Chamaecyparis lawsoniana			(4.3)	(6.4)	(222.8)
Vaccinium ovatum					
ALRU/RUSP/CAOB-LYAM3	2	30.5	47.5	39.6	535.1
Alnus rubra			(3.8)	(4.0)	(49.8)
Rubus spectabilis					
Carex obnupta					
Lysichiton americanum					
PISI/VAOV2	1	44.9	136.8	45.9	64.2
Picea sitchensis					
Vaccinium ovatum					
TSHE/RHMA3-VAOV2	7	323.8	37.8	42.6	864.9
Tsuga heterophylla			(4.6)	(11.3)	(208.6)
Rhododendron macrophyllum					
Vaccinium ovatum					
Woodland	2	46.0	14.4	16.7	1535.2
			(3.4)	(2.9)	(160.5)
Shrubland	1	23.5	44.0	91.8	147.5
UNCLASSED	20	230.3			

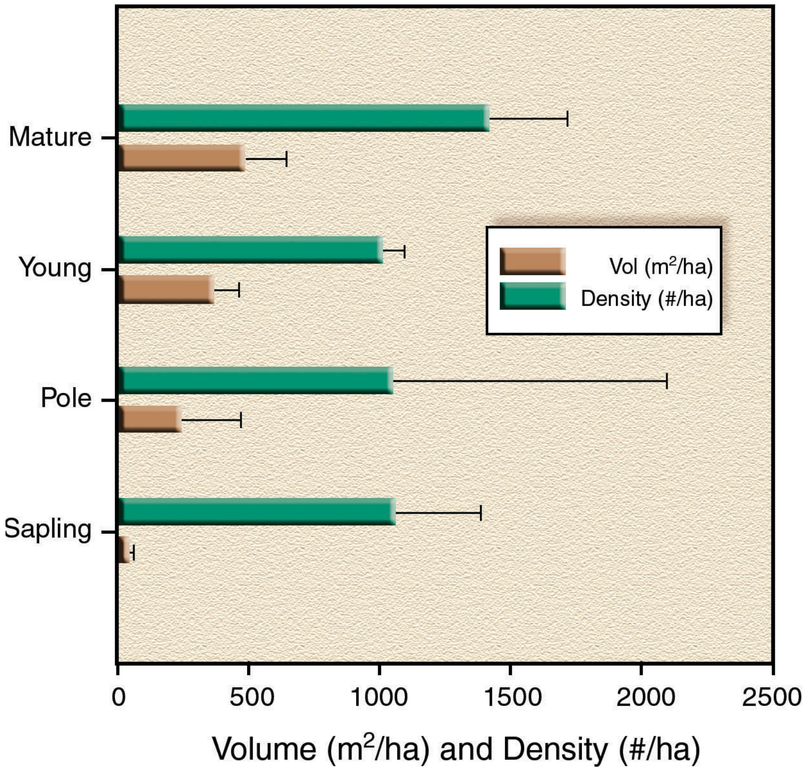


Fig. 4.9. Volume and density of downed wood within different forest seral stages in the South Slough NERR, OR. Values indicate means (SE).

establishment of several exotic invasive species, including gorse (*Ulex europaeus*), scotch broom (*Cytisus scoparius*), and Himalayan blackberry (*Rubus armeniacus [R. discolor]*).

4.3.5 Downed Wood and Snags

Downed wood provides numerous ecosystem functions in Pacific northwest forests including cover for wildlife, support of insect prey populations, modified microclimates for ectotherms, and nurse logs for western hemlock and other tree species (Maser *et al.*, 1988).

Standing snags provide nesting, roosting and foraging sites for numerous insectivorous and cavity-nesting wildlife species, as well as resident sites for their invertebrate prey. Trees that die before or during a catastrophic disturbance event are typically the primary source of downed wood and snags for the first 100 yrs of stand succession (Spies *et al.*, 1988). These dead structural elements persist through natural disturbances, but often were removed during commercial timber harvests. The majority of upland forest management areas within the South Slough NERR were harvested within the last century. Some of the historic downed wood was most likely burned during post-harvest operations or mechanically disturbed by tractor-based logging and skyline tree skidding approximately 20-50 years ago.

Upland areas of the South Slough NERR contain levels of downed wood (decay classes, and volumes) that are comparable to naturally regenerating stands in the Oregon Coast Range (Hansen *et al.*, 1991, Spies and Franklin, 1991; Table 4.18, Figure 4.9). Decay classes for downed wood average 3-4 across the sapling, pole, young, and mature forest seral stages. Although the volumes of downed wood within the Reserve are comparable to other coastal sites, densities of downed wood (# ha^{-1}) are greater within South Slough NERR in comparison to naturally regenerating stands. This implies that the source population of downed wood includes a higher number of short pieces compared to naturally regenerating stands. This may be explained by the high frequency of residual logging debris and selective harvest practices which left many stems cut but not removed from the forest stands.

Snag densities in the South Slough NERR are generally very low in comparison to naturally regenerating stands (Table 4.19, Figure 4.10). Pole-stage areas in

Table 4.18. Summary characteristics for downed wood within the South Slough NERR, OR. Values indicate means (SE).

Sample size ⟶	Sapling 6	Pole 26	Young 35	Mature 6
Downed Wood				
Volume (m^2/ha)	44.5 (16.5)	235.6 (79.0)	356.5 (109.9)	482.3 (163.7)
Density (# / ha)	1057.7 (328.4)	1050.3 (148.7)	1002.7 93.5)	1410.2 (308.8)
Decay class	4.2 (0.3)	3.3 (0.1)	3.4 (0.2)	3.5 (0.5)

the Reserve are the exception where they exhibit an elevated snag density. Low snag densities may be due to disease or suppression mortality in very dense stands, or to lower utilization standards for harvests at the time the sites were last logged. Snags that do exist within the Reserve are generally hard (mean decay class 1 in mature areas and decay class 2 in other areas), suggesting that most snags were removed during stand conversions. The existing snags are most likely a result of recent tree mortality due to competitive suppression. The frequency of small cavities (5 inches in diameter or smaller) in snags is relatively low within the South Slough NERR (Table 4.19), and larger cavities that are suitable for cavity-nesting birds are very limited within the upland forest management areas.

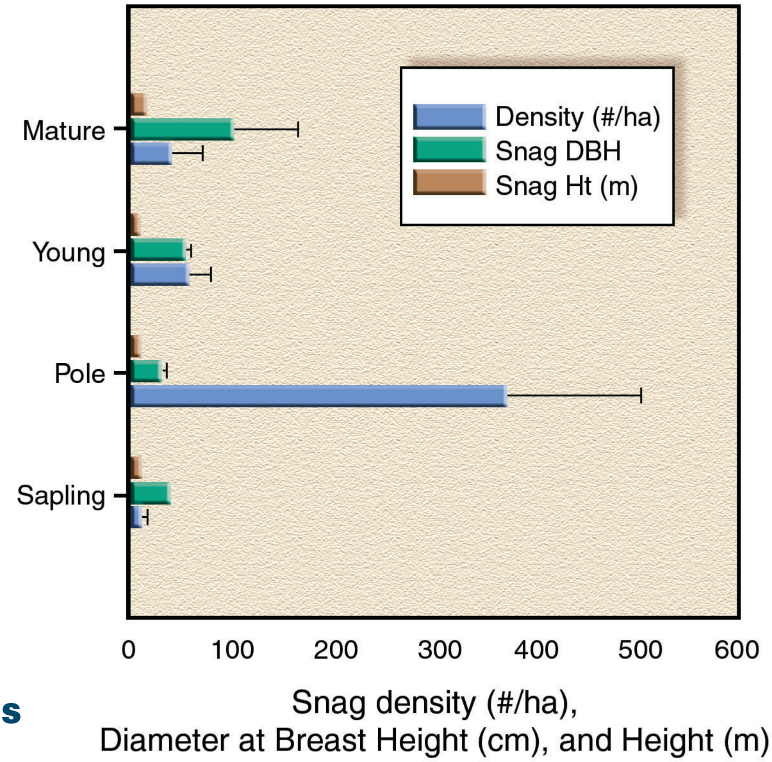


Fig. 4.10. Densities and sizes of snags within different forest seral stages in the South Slough NERR, OR. Values indicate means (SE).

4.3.6 Wildlife Communities in Upland Forests

Systematic sampling of upland faunal communities has not been conducted within the South Slough NERR. Vertebrate assemblages that inhabit coastal temperate forests of the Pacific northwest region have been described in a general manner (Bunnel and Chan-Mcleod, 1996; Brown, 1985), and Oregon's coastal fauna has been characterized for specific groups including mammals (Maser *et al.*, 1981; Corn and Bury, 1991), amphibians (Bury *et al.*, 1991; Corn and Bury, 1991), reptiles (Nussbaum *et al.*, 1983) and birds (Carey *et al.*, 1991).

4.3.6.a General Composition of Wildlife Communities

Upland faunal species that inhabit the South Slough NERR can be categorized into several large functional groups (Bunnel *et al.*, 1997). Upland habitat areas support: (a) vertebrate wildlife general-

Table 4.19. Summary characteristics for snags within different forest seral stages in the South Slough NERR, OR. Values indicate means (SE).

Snags	Sapling	Pole	Young	Mature
Sample size ⟶	1	17	16	2
Density (# / ha)	8.2 (8.2)	369.1 (134.0)	54.7 (24.6)	39.0 (32.4)
Decay class	2.0	2.1 (0.2)	2.1 (0.3)	1.2 (0.2)
Snag DBH (cm)	34.5	30.2 (5.4)	52.8 (6.8)	99.6 (65.8)
Snag height (m)	8.5	7.7 (0.7)	7.7 (1.7)	13.3
Cavities (<2 in.) %	1.0	0.6 (0.1)	0.5 (0.1)	0.2 (0.2)
Cavities (2-4 in.) %	0	0.2 (0.1)	0.3 (0.1)	0 0
Cavities (>5 in.) %	0	0.1 (0.1)	0.1 (0.1)	0 0

ists (species that use a wide variety of habitat types), (b) birds that nest in shrubs, (c) species associated with deciduous cover, (d) cavity users, (e) species associated with downed wood, (f) large game species, (g) sensitive species, and (h) species that require specialized habitats.

A diverse assemblage of birds occur in the upland and lowland habitats of the Oregon Coast Range and are potential permanent or temporary residents of the South Slough watershed (Table 4.20). The western region of Oregon is inhabited by 24 species birds that nest in shrubs, 82% of which are neotropical migrants (Bunnel *et al.*, 1997). South Slough NERR contains a large component of understory shrubs and significant brush areas that provide an abundance of understory forage habitat for birds. Limited evidence is available, however, to demonstrate that the neotropical migrant birds in Oregon's western and coastal forests require significant interior areas (Bunnell *et al.*, 1997). Consequently, the extensive shrub cover within the South Slough watershed makes it likely that the shrub-nesting functional group of birds is probably well represented in the South Slough NERR.

Canopy cover provided by deciduous trees is used extensively for nesting and forage habitat by a variety of vertebrates within Oregon's western forests. In addition to the shrub-nesting birds, 51 species of vertebrates are strongly associated with deciduous canopy cover (Bunnell *et al.*, 1997). Insectivorous birds are more diverse and abundant than insectivorous mammals, and the elevated frequency of cavities in hardwood trees supports a greater abundance of insects compared to softwood trees. As a result, bird communities typically have stronger associations with deciduous trees than do mammals. Upland habitats within the South Slough NERR include several red alder–dominated management areas, and red alder is present in most coniferous forest management areas (and all riparian areas). Forest canopy cover levels in deciduous forests probably do not limit the diversity or density of vertebrates within the Reserve.

A diverse assemblage of mammals occur in the upland and lowland habitats of the Oregon Coast Range and are potential residents of the South Slough watershed (Table 4.21). About 25% of the vertebrate fauna from coastal British Columbia are known to utilize cavities in trees or snags at some point in their life-histories (Bunnell *et al.*, 1991). In Oregon, over 50 vertebrate species utilize cavities, including birds, mammals and amphibians (Bunnell *et al.*, 1997). Snags and dying trees provide sites for birds to nest, roost, and perch, and the decayed wood provides habitat for wood-boring insects. Woodpeckers, particularly the pileated woodpecker (*Dryocopus pileatus*), create habitat for other species by excavating cavities in trees. The South Slough NERR is relatively depauperate in large snags. Moreover, the low numbers of snags and dying trees that do exist within the Reserve do not contain many cavities, and large cavities are exceptionally rare. As a result, the abundance of species that depend on cavities for nesting are probably low within the Reserve in comparison with historic levels.

Downed wood supports 15-25% of the coastal forest species in the Pacific northwest region (Bunnell *et al.*, 1991), and over 69 species in western Oregon utilize downed wood at some point in their life histories (Bunnell *et al.*, 1997). The majority of species that depend on downed wood are mammals, although several amphibians also have strong associations with fallen logs and decaying tree limbs. Downed wood provides cover for vertebrates and their prey within the South Slough NERR, and probably serves as a shelter area for reproduction. Downed wood is also conducive to a modified microclimate which is important for amphibian thermoregulation. The volumes of downed woody material in the South Slough NERR are roughly comparable to levels of downed wood in naturally-occurring stands. Therefore, downed wood levels are probably not currently a limiting factor for support of vertebrate populations in the Reserve. The predominance of early to mid-seral stage forest stands within the Reserve, however, indicates that the upland forests will reach a point in time when the existing downed wood will decay and become sub-optimal habitat. Moreover, the remaining large trees will not mature and senesce rapidly to form new snags and downed logs. This point will present a critical habitat bottleneck for species that are dependent on downed woody materials and may lead to population declines. In addition, much of the downed wood that is currently available in the South Slough NERR has been left by logging operations and/or mechanically disturbed by site preparation (burning) or bulldozer activities. It is unclear whether the existing downed wood (much of it with limited bark cover or otherwise mechanically compromised) will provide adequate cover and sufficient microclimatic buffering to be adequate for habitat use by wildlife.

Table 4.20. Species list of breeding birds that potentially occur in the South Slough watershed and adjacent coastal areas (adapted from Csuti *et al*., 1997).

Common name	*Genus species*
Seabirds	
Fork-tailed storm-petrel	*Oceanodroma furcata*
Leach's storm-petrel	*Oceanodroma leucorhoa*
Double-crested cormorant	*Phalacrocorax auritus*
Brandt's cormorant	*Phalacrocorax penicillatus*
Pelagic cormorant	*Phalacrocorax pelagicus*
Western gull	*Larus occidentalis*
Common murre	*Uria aalge*
Pigeon guillemot	*Cepphus columba*
Marbled murrelet	*Brachyramphus marmoratus*
Rhinoceros auklet	*Cerorhinca monocerata*
Tufted puffin	*Fratercula cirrhata*
Wading birds	
Great blue heron	*Ardea herodias*
Green heron	*Butorides virescens*
Waterfowl	
Wood duck	*Aix sponsa*
Mallard	*Anas platyrhynchos*
Blue-winged teal	*Anas discors*
Cinnamon teal	*Anas cyanoptera*
Hooded merganser	*Lophodytes cucullatus*
Common merganser	*Mergus merganser*
American coot	*Fulica americana*
Raptors	
Turkey vulture	*Cathartes aura*
Osprey	*Pandion haliaetus*
Sharp-shinned hawk	*Accipiter striatus*
Cooper's hawk	*Accipiter cooperii*
Red-tailed hawk	*Buteo jamaicensis*
American kestrel	*Falco sparverius*
Peregrine falcon	*Falco peregrinus*
Gallinaceous birds	
Ring-necked pheasant	*Phasianus colchicus*
Blue grouse	*Dendragapus obscurus*
Ruffed grouse	*Bonasa umbellus*
California quail	*Callipepla californica*
Mountain quail	*Oreortyx pictus*
Shorebirds	
Semipalmated plover	*Charadrius semipalmatus*
Killdeer	*Charadrius vociferous*
Black oystercatcher	*Haematopus bachmani*
Spotted sandpiper	*Actitis macularia*
Pigeons and Doves	
Band-tailed pigeon	*Columba fasciata*
Mourning dove	*Zenaida macroura*

Table 4.20 Continued next page

Table 4.20 Continued

Common name	*Genus species*
Owls	
Barn owl	*Tyto alba*
Western screech-owl	*Otus kennicottii*
Great horned owl	*Bubo virginianus*
Northern pygmy-owl	*Glaucidium gnoma*
Spotted owl	*Strix occidentalis*
Barred owl	*Strix varia*
Northern Saw-whet owl	*Aegolius acadicus*
Nighthawks	
Common nighthawk	*Chordeiles minor*
Swifts and swallows	
Vaux's swift	*Chaetura vauxi*
Purple martin	*Progne subis*
Tree swallow	*Tachycineta bicolor*
Violet-green swallow	*Tachycineta thalassina*
Cliff swallow	*Hirundo pyrrhonota*
Barn swallow	*Hirundo rustica*
Hummingbirds	
Anna's hummingbird	*Calypte anna*
Rufous hummingbird	*Selasphorus rufus*
Kingfishers	
Belted kingfisher	*Ceryle alcyon*
Woodpeckers	
Red-breasted sapsucker	*Sphyrapicus ruber*
Downy woodpecker	*Picoides pubescens*
Hairy woodpecker	*Picoides villosus*
Northern flicker	*Colaptes auratus*
Pileated woodpecker	*Dryocopus pileatus*
Passerines	
Olive-sided flycatcher	*Contopus borealis*
Western wood-pewee	*Contopus sordidulus*
Willow flycatcher	*Empidonax traillii*
Pacific-slope flycatcher	*Empidonax difficilis*
Western kingbird	*Tyrannus verticalis*
Gray jay	*Perisoreus Canadensis*
Steller's jay	*Cyanocitta stelleri*
American crow	*Corvus brachyrhynchos*
Common raven	*Corvus corax*
Black-capped chickadee	*Parus atricapillus*
Chestnut-backed chickadee	*Parus rufescens*
Bushtit	*Psaltriparus minimus*
Red-breasted nuthatch	*Sitta canadensis*
White-breasted nuthatch	*Sitta carolinensis*
Brown creeper	*Certhia americana*
Bewick's wren	*Thryomanes bewickii*
House wren	*Troglodytes aedon*
Winter wren	*Troglodytes troglodytes*

Table 4.20 Continued next page

Table 4.20 Continued

Common name	Genus species
Passerines (continued)	
Marsh wren	*Cistothorus palustris*
American dipper	*Cinclus mexicanus*
Golden-crowned kinglet	*Regulus satrapa*
Western bluebird	*Sialia mexicana*
Swainson's thrush	*Catharus ustulatus*
American robin	*Turdus migratorius*
Varied thrush	*Ixoreus naevius*
Wrentit	*Chamaea fasciata*
Cedar waxwing	*Bombycilla cedrorum*
European starling	*Sturnus vulgaris*
Solitary vireo	*Vireo solitarius*
Hutton's vireo	*Vireo huttoni*
Warbling vireo	*Vireo gilvus*
Orange-crowned warbler	*Vermivora celata*
Nashville warbler	*Vermivora ruficapilla*
Yellow warbler	*Dendroica petechia*
Yellow-rumped warbler	*Dendroica coronata*
Black-throated gray warbler	*Dendroica nigrescens*
Hermit warbler	*Dendroica occidentalis*
Macgillivray's warbler	*Oporornis tolmiei*
Common yellowthroat	*Geothlypis trichas*
Wilson's warbler	*Wilsonia pusilla*
Western tanager	*Piranga rubra*
Black-headed grosbeak	*Pheucticus melanocephalus*
Spotted towhee	*Pipilo maculates*
Savannah sparrow	*Passerculus sandwichensis*
Song sparrow	*Melospiza melodia*
White-crowned sparrow	*Zonotrichia leucophrys*
Dark-eyed junco	*Junco hyemalis*
Red-winged blackbird	*Agelaius phoeniceus*
Brewer's blackbird	*Euphagus cyanocephalus*
Brown-headed cowbird	*Molothrus ater*
Purple finch	*Carpodacus purpureus*
House finch	*Carpodacus mexicanus*
Red crossbill	*Loxia curvirostra*
Pine siskin	*Carduelis pinus*
American goldfinch	*Carduelis tristis*

4.3.6.b Game Species

Common upland large game species that inhabit the South Slough NERR include black-tailed deer (*Odocoileus hemonius columbianus*), Roosevelt elk (*Cervus elaphus roosevelti*) and the North American black bear (*Ursus americanus*). These species are influenced by levels of forage quality/quantity and, to some extent by thermal refugia and security cover. High levels of forage shrub species currently occur within the Reserve, along with significant forested areas and relatively low levels of disturbance. Bear populations in the South Slough watershed are probably limited principally by home range size. An individual male bear home range size can be as large as 6 km (Maser *et al.*, 1981).

Table 4.21. Mammals of the Lower Columbia Bioregion that potentially occur in the South Slough watershed and adjacent coastal areas (adapted from Csuti *et al.*, 1997).

Common name	*Genus species*
Marsupials	
Virginia opossum	*Didelphis virginiana*
Shrews	
Vagrant shrew	*Sorex vagrans*
Fog shrew	*Sorex sonomae*
Pacific shrew	*Sorex pacificus*
Pacific marsh shrew	*Sorex bendirii*
Trowbridge's shrew	*Sorex trowbridgii*
Moles	
Shrew mole	*Neurotrichus gibbsii*
Townsend's mole	*Scapanus townsendii*
Coast mole	*Scapanus orarius*
Bats	
California myotis	*Myotis californicus*
Yuma myotis	*Myotis yumanensis*
Little brown myotis	*Myotis lucifugus*
Long-legged myotis	*Myotis volans*
Fringed myotis	*Myotis thysanodes*
Long-eared myotis	*Myotis evotis*
Silver-haired bat	*Lasionycteris noctivagans*
Big brown bat	*Eptesicus fuscus*
Hoary bat	*Lasiurus cinereus*
Rabbits	
Brush rabbit	*Sylvilagus bachmani*
Snowshoe hare	*Lepus americanus*
Rodents	
Mountain beaver	*Aplodontia rufa*
Townsend's chipmunk	*Tamias townsendii*
California ground squirrel	*Spermophilus beecheyi*
Douglas' squirrel	*Tamiasciurus douglasii*
Northern flying squirrel	*Glaucomys sabrinus*
Western pocket gopher	*Thomomys mazama*
American beaver	*Castor canadensis*
Deer mouse	*Peromyscus maniculatus*
Dusky-footed woodrat	*Neotoma fuscipes*
Bushy-tailed woodrat	*Neotoma cinerea*
Western red-backed vole	*Clethrionomys californicus*
White-footed vole	*Phenacomys albipes*
Red tree vole	*Phenacomys longicaudus*
Townsend's vole	*Microtus townsendii*
Long-tailed vole	*Microtus longicaudus*
Creeping vole	*Microtus oregoni*
Muskrat	*Ondatra zibethicus*
Norway rat	*Rattus norvegicus*
House mouse	*Mus musculus*
Pacific jumping mouse	*Zapus trinotatus*

Table 4.21 Continued next page

Table 4.21 Continued

Common name	Genus species
Common porcupine	*Erethizon dorsatum*
Nutria	*Myocastor coypus*
Carnivores	
Coyote	*Canis latrans*
Common gray fox	*Urocyon cinereoargenteus*
Black bear	*Ursus americanus*
Common raccoon	*Procyon lotor*
American marten	*Martes americana*
Fisher	*Martes pennanti*
Ermine	*Mustela erminea*
Long-tailed weasel	*Mustela frenata*
Mink	*Mustela vison*
Western spotted skunk	*Spilogale gracilis*
Striped skunk	*Mephitis mephitis*
Northern river otter	*Lutra canadensis*
Mountain lion	*Felis concolor*
Bobcat	*Lynx rufus*
Ungulates	
Elk	*Cervus elaphus*
Black-tailed deer	*Odocoileus hemionus*

4.3.6.c Sensitive Species

Many sensitive species in Oregon are dependent on structural and compositional characteristics of forest habitats. Of these sensitive species, 22 species are cavity users, 14 species are strongly associated with downed wood, 12 species prefer structural heterogeneity, and 7 species require large live trees. Large live trees and snags are relatively rare within the South Slough NERR, and the Reserve probably offers only marginally-suitable habitat for structure-dependent species. In addition, historic timber havests have skewed the distribution of forest size and age classes in favor of mid-successional stages. Consequently, forest stands within the Reserve are similar in age class both between and within the individual forest management areas. This homogeneity of forest size structure contributes to low wildlife diversity (Bunnell *et al.*, 1997). Homogenous landscapes cannot support sensitive species that require spatial heterogeneity.

Several sensitive species may be present in the upland habitat areas of the South Slough NERR. Bald eagle (*Haliaeetus leucocephalus*) are known to nest along the shoreline of the South Slough estuary, and the Reserve may provide temporary habitat for marbled murrelet (*Brachyramphus marmoratus*), northern goshawk (*Accipiter gentilis*), northern pygmy owl (*Glaucidium gnoma*), peregrine falcon (*Falco peregrinus anatum*), purple martin (*Progne subis*), pileated woodpecker (*Dryocopus pileatus*), northern spotted owl (*Strix occidentails caurina*), sharp-tailed snake (*Contia tenuis*), American marten (*Martes americana*), and western gray squirrel (*Sciurus griseus*). Each of these species has specific habitat needs, which may or may not be met by the upland forested communities within the South Slough NERR. For example, the Reserve boundaries encompass only a small complement of relatively undisturbed late-seral forest patches in close proximity to the ocean and the Coos estuary. These patches of mature forest may provide nesting habitat for the marbled murrelet. Many of the other sensitive species noted above require special habitat elements such as cliffs or large snags or large tracts of undisturbed habitat that are not adequately encompassed by the existing administrative boundaries of the South Slough NERR.

Chapter 5

Adaptive Management of the South Slough Estuarine Ecosystem

5.1 Adaptive Coastal and Estuarine Ecosystem Management

Adaptive ecosystem management has emerged over the past 30 years as an innovative and flexible outcome-based paradigm for the stewardship of natural resources (Holling, 1978; Halbert, 1993; Grumbine, 1997). Under the adaptive management process, natural resource decisions are considered as administrative experiments that are designed to gather and integrate interdisciplinary information into dynamic models that make predictions about the impacts of alternative policies and management practices. The adaptive ecosystem management process has been widely adopted as an avenue for decision making by several federal and state land management and regulatory agencies, and serious attempts have been made to implement the adaptive management approach within federally-managed forests of the Pacific northwest bioregion (Bormann *et al.*, 1993; USFS, 1994).

Adaptive ecosystem management has also been applied as a flexible tool for management of coastal zones and estuaries (Zedler and Nyden, 1995; Simenstad *et al.*, 1997; Thom, 1997). For example, adaptive decision making is a central paradigm of long-term management of the system of estuaries encompassed by the US Environmental Protection Agency – National Estuary Program (Kennish, 2000), and it is an essential element of regulatory policies that control river flow within the Columbia River estuary (Lee 1993; Lee and Lawrence, 1986), establish land use policies to reduce nutrient additions to Chesapeake Bay (Hennessey, 1994), restore wetland functions and values within the Florida everglades (Walters *et al.*, 1992; Davis and Ogden, 1994), and assess the efficacy of fish recovery policies within the Pacific northwest coastal zone (McAllister and Peterman, 1992; Smith *et al.*, 1998).

The adaptive management approach also holds great promise for application to the watershed of the Coos estuary and the nearshore coastal zone where the cooperative partnership between the National Oceanic and Atmospheric Administration (NOAA) and the Oregon Department of State Lands (ODSL) focus on management of the South Slough National Estuarine Research Reserve (NERR) as a core estuarine adaptive management area. Adaptive coastal and estuarine ecosystem management should be considered for the South Slough NERR as an integrative and experimental approach to resource management within the coastal watershed, estuarine tidal basin, and immediate area of marine influence. Although several innovative management projects and scientific studies have been completed within the South Slough estuary, the framework for adaptive coastal and estuarine ecosystem management is still in its infancy within the South Slough estuarine ecosystem.

5.1.1 Definition of Adaptive Coastal and Estuarine Ecosystem Management

Adaptive Coastal and Estuarine Ecosystem Management is defined for the South Slough estuary as:

an integrative process to improve local and regional coastal and estuarine management strategies and practices by the acquisition of credible information from the outcome of operational programs carried out within the South Slough estuary. The adaptive coastal and estuarine ecosystem management approach recognizes the importance of fundamental environmental processes and scientific uncertainty to evaluate alternative hypotheses about estuarine ecosystem functions, and builds upon a rigorous combination of management, research, and monitoring information to formulate successful policies and improve management programs.

5.1.2 Context for Information Gathering and Synthesis

The conceptual design for the South Slough estuary adaptive coastal and estuarine ecosystem management approach has ten essential components (Figure 5.1). At a fundamental level, the approach is based upon an *accurate characterization of the estuarine and watershed habitats* and *a fundamental understanding of the estuarine ecological processes.* These essential understandings provide a background and context for development of the adaptive management approach that will integrate natural variability and anthropogenic disturbance within the watershed, tidal basin, and in the area of marine influence. The approach will also seek to identify important ecotones that serve as boundaries between the marine, estuarine, wetland, and upland habitats, as well as the diverse floral and faunal communities that inhabit distinct ecosystem components.

The process begins when *meaningful and relevant questions* are posed by the academic community, resource management agencies, and members of the public. Questions are focused, refined, and used to design a series of *scientific research projects, experimental management practices, and practical demonstration projects.* Scientific research and environmental monitoring are undertaken as a systematic inquiry to investigate inherent variability, natural patterns and processes, and to produce accurate technical information about correlative and causative relationships. Experimental management practices are initiated to address questions regarding the effectiveness of management operations and actions. Demonstration projects incorporate new empirical information and conceptual design elements to develop practical solutions to management problems including accelerated restoration of lost ecological functions in degraded habitats and establishment of Best Management Practices (BMPs) designed to diminish the detrimental effects of human activities in the tidal basin and watershed.

Credible baseline understandings are combined with results from scientific research, management practices, and demonstration projects to yield a new synthesis; *essential management information* is the primary product of the adaptive coastal and estuarine ecosystem management process. This essential management information is used to produce a new series of questions, and to improve and adapt existing management practices. Essential management information is also used to develop *predictive and adaptive management models* that forecast assumptions and hypotheses regarding the outcome of human-mediated activities on components of the estuarine and coastal ecosystem. Several different methods are used for *information exchange, education, and outreach*, including workshops, tours, seminars, publications, interpretive displays, and media events. The predictive and adaptive management practices are tracked by subsequent *monitoring activities* to evaluate project compliance, effectiveness, and outcomes with regard to their stated goals and objectives.

Essential components of the adaptive coastal and estuarine ecosystem management approach include:

- Habitats, Communities & Fundamental Estuarine Processes
- Meaningful Questions
- Scientific Research & Monitoring
- Experimental Management Practices
- Practical Demonstration Projects
- Credible Baseline Understanding
- Essential Management Information
- Information Exchange, Education & Outreach
- Predictive & Adaptive Management Models
- Monitoring Activities

It is important to acknowledge that although the adaptive ecosystem management approach is designed to increase knowledge and enhance information exchange, not all of the anticipated benefits have been realized (Mclain and Lee, 1996). Site-specific reviews of natural resource management programs illustrate that the adaptive approach is currently flawed by excessive reliance on linear ecosystem models, disconsideration of non-scientific forms of knowledge, and inadequate attention to intrinsic policy processes that promote consensus among diverse stakeholders. Adaptive management efforts will become more effective when they incorporate knowledge from multiple sources, develop and utilize multiple ecosystems models, and support enhanced cooperation among the ecosystem stakeholders (Mclain and Lee, 1996).

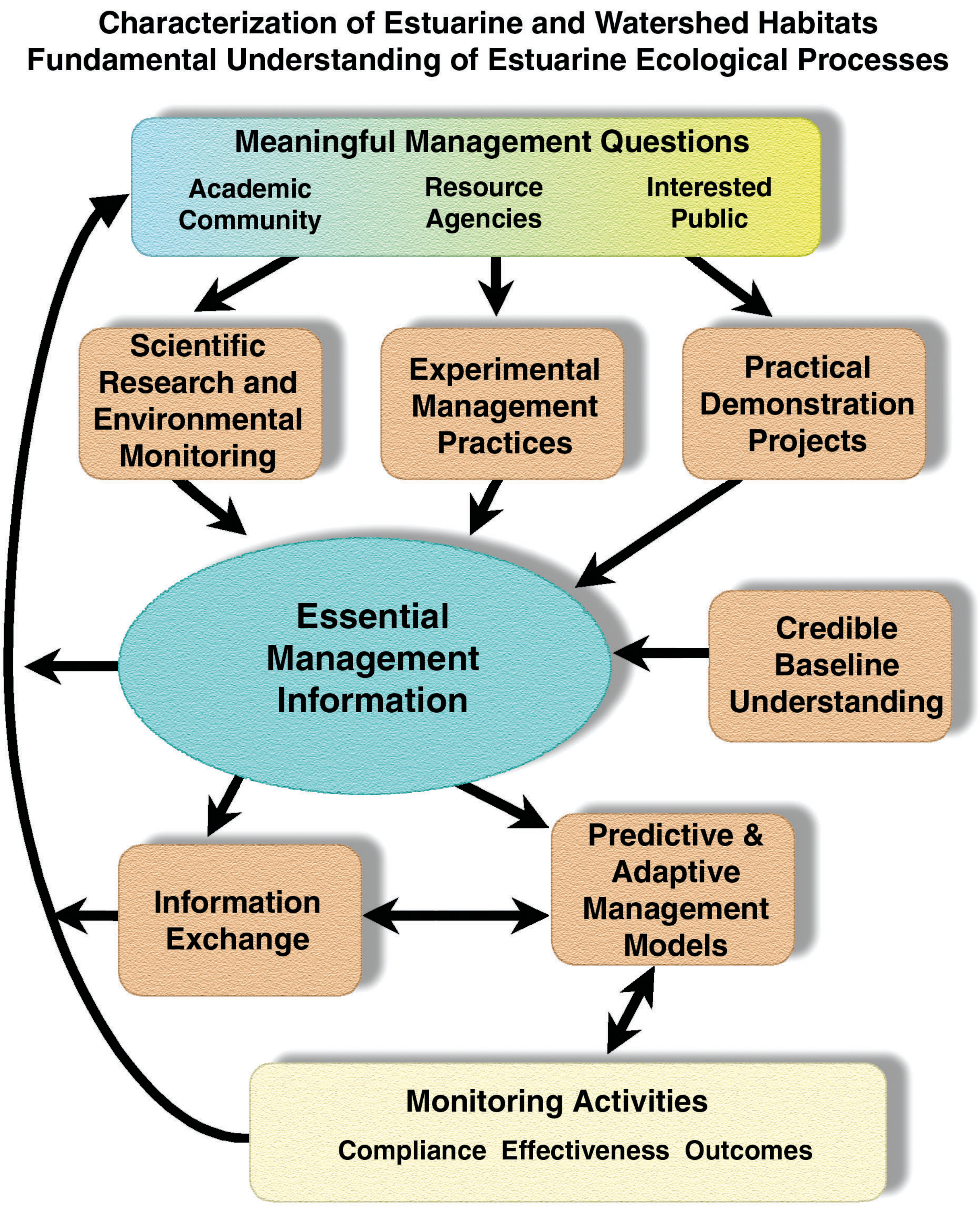


Figure 5.1. Conceptual design for an adaptive coastal and estuarine ecosystem management approach for the South Slough estuary.

5.2 Delineation and Characterization of Estuarine and Upland Habitats

Habitat assessment and characterization is an ongoing process within the South Slough National Estuarine Research Reserve (NERR). Cursory descriptions of the estuarine habitats were initially assembled during the nomination process that lead to designation of the South Slough NERR in 1974. More detailed descriptions of estuarine and upland habitats were compiled from a variety of sources during preparation of the South Slough NERR Management Plans (1984, 1994, 2005). Finally, delineation and characterization of the estuarine and upland habitats was carried out within the administrative boundaries of the South Slough NERR (1991-94) in preparation for this site profile document. Systematic surveys of terrestrial and aquatic habitats and communities have not yet been completed for the entire South Slough watershed, estuary, and area of marine influence.

5.2.1 Hierarchical Habitat Classification

A multi-disciplinary and hierarchical habitat classification program is needed within the South Slough NERR, the upland portions of the South Slough watershed, and the immediate area of nearshore marine influence in order to provide a fundamental understanding of habitat complexity and a foundation for adaptive coastal and estuarine ecosystem management. Delineation of distinct habitat types, including critical habitat for sensitive species, involves complex analyses of many different layers of information. Important marine, estuarine and upland habitat components can be identified in a hierarchical manner based primarily on the distinction between aquatic and terrestrial environments, and on their hydrogeomorphology, bathymetry, and other earthform features (Allee *et al.*, 2000). Further distinction of these components can be assessed according to information about relevant environmental factors such as hydrodynamic exposure, substratum, vegetation type, faunal assemblages, and proximity to other known habitats and communities. Other modifiers, such as edaphic soil conditions, hill slope aspect, tidal inundation, and position along the estuarine gradient provide a framework for interpretation of ecological function (Allee *et al.*, 2000).

5.2.2 Watershed Land-Use and Land-Cover Classifications

The South Slough NERR program for habitat delineation and land-use classification should be patterned after the NOAA Coastal Change Analysis Program (C-CAP; Cross and Thomas 1992; Haddad 1992) or other methodological processes that integrate multiple sources of descriptive and quantitative spatial information. Systematic surveys of the marine, estuarine and upland habitats should be carried out as a cooperative interagency effort to detect and quantify spatial cover for the coastal upland, emergent wetland, tidalflats, submerged aquatic vegetation, and subtidal components of the Reserve, and to evaluate changes in these habitats over time. Characterization of the South Slough NERR and its associated watershed and Estuarine Drainage Area (EDA) should be carried out with a combination of digital remote sensor data, low-altitude aerial photography, and water-based hydroacoustic data that is coupled with *in situ* ground-truth measurements that include accurate Global Positioning System (GPS) coordinates for attribute information collected in the field.

Data files generated by the hierarchical habitat delineations and land-use surveys should be transferred to the centralized South Slough NERR Protected Area Geographic Information System (PAGIS). The PAGIS will be used to manage the spatial datasets and visualize the extent of changes in the estuary, coastal wetland habitats, and the adjacent uplands. Digital GIS files, spatial data, and other important attributes can then be shared directly with other users and stakeholders within the context of the entire Coos estuary, Coos EDA, and Coos watershed via the Dynamic Estuary Management and Information System (DEMIS). DEMIS is an example of an existing cooperative multiagency compilation of spatial data and related attribute information into common GIS files for the entire Coos watershed.

5.2.3 Context for Estuarine Protected Area Design

Initial designation of the administrative boundaries of the South Slough NERR was driven more by opportunity and visual aesthetics than by rigorous scientific evaluation and conservation design. Contemporary understandings of landscape-level connections, aquatic and terrestrial biodiversity (at the ascending multiple levels of genes, species, populations, and communities), and regional understandings of metapopulation dynamics, wildlife corridors, and coastal ecosystem functions should all be incorporated into the design elements for marine and estuarine protected areas (Zacharias and Roff, 2000; Roff and Taylor, 2000). Moreover, the process of gap analysis (Scott *et al.*., 1993) should be completed both within and outside the existing Reserve boundaries to identify rare species and distinctive communities and fill missing elements of the existing South Slough NERR as a core estuarine management area. It is likely that the optimal design for the land-margin ecosystem that encompasses the South Slough NERR will include additional elements of the watershed sub-basin and nearshore area of marine influence as a hybrid between the open network design for marine protected areas and the core-buffer design for terrestrial protected areas (Noss and Cooperrider, 1994).

Systematic characterization of the South Slough NERR and its associated watershed and area of marine influence should be carried out as a prerequisite to the evaluation of overall reserve design and performance. In particular, hyperspectral imagery and digital data should be acquired and analyzed to map marine, estuarine and upland habitats throughout the South Slough land-margin ecosystem with sufficient precision and accuracy to detect ecologically important structural and biotic elements of the coastal watershed landscape. Landsat Multispectral Scanner (MSS) data, Landsat Thematic Mapper (TM) data, SPOT high resolution visible (HRV) images, IKONOS data and LIDAR imagery should be explored as sources of digital data to detect major land-use categories and coastal habitats at different spatial scales (*i.e.* 1-30 m resolution). Moreover, new orthorectified aerial photography (true color and color infrared at 1:12,000 resolution) should be acquired every 5-7 years, and the images should be regularly updated into the South Slough NERR PAGIS. *In situ* ground-truth measurements of habitats, communities, and species should be completed on a semi-annual basis within permanent transects and photopoints as well as in a probabilistic manner that reflects the spatial extent and location of different habitat elements.

5.3 Restoration of Lost Habitat Functions and Values in the South Slough Watershed

Terrestrial and aquatic habitat elements of the South Slough coastal watershed are complex assemblages of an interconnected land-margin ecosystem. Physical and biotic interactions among the distinct watershed elements (upland forests, riparian corridors, emergent freshwater and salt marshes, tidal flats, and channels) and the nearshore ocean occur across ecotones and add further complexity to the analysis of ecosystem functions. Furthermore, processes that dictate ecosystem functions within single habitat components must also be studied within the context of the larger land-margin system.

In a similar fashion, restoration and enhancement projects that seek to regain lost or degraded structural and functional attributes in estuarine and coastal habitats should be undertaken within the broader context of the South Slough watershed. Several experimental efforts to restore upland, riparian, and tidal wetland habitats have been initiated within the South Slough NERR that incorporate landscape-level planning and links among adjacent habitats.

5.3.1 Analysis and Restoration of the South Slough Watershed

Ecological integrity of the South Slough watershed has diminished over the past century due to concurrent logging operations, road building, conversion of wetlands to agricultural purposes, commercial mariculture, residential development, shoreline industry, and other large-scale perturbations (Rumrill and Cornu, 1995). Although these extractive uses and historic alterations of the shoreline and adjacent watershed provided substantial economic benefits to the local community, injuries to the ecological integrity of the South Slough ecosystem are largely symptomatic of the widespread loss, alteration, and degradation of coastal habitats on a regional scale (Boule and Bierly, 1987; Good, 1987; Corn and Bury, 1989; Thomas *et al.*, 1993) and throughout the nation (Mitsch and Gosselink, 1986; Field *et al.*, 1991; Seneca and Broome, 1992). Recognition of abiotic and biotic links between upland coastal forests, wetland habitats, and the estuarine tidal basin contributes to the need for innovative restoration and enhancement techniques designed to repair coastal drainage basins and accelerate restoration of coastal wetland habitats (Zedler, 1990; National Research Council, 1992; Reeves and Sedell, 1992; Simenstad and Thom, 1992; Maser and Sedell, 1994).

5.3.2 Elements of the South Slough Watershed Restoration Plan

Forest communities, streams and tidal wetlands have been heavily impacted by historic management practices on both public and private lands within the South Slough watershed. The cumulative effects of selective and clear-cutting of streamside forests, inadequate riparian buffer areas, removal of woody debris from channels, and road construction contributed to increased streamflow and sediment redistribution (Harr and Nichols, 1993; Maser and Sedell, 1994). These activities have negative impacts on spawning habitat for anadromous fish and diminish critical habitat for resident and migratory shorebirds (Spies and Franklin, 1991). Remedial actions designed to restore lost structural and functional elements of the South Slough watershed are integral to the reestablishment of links between estuarine and upland habitats, recovery of native fish, provision of habitats for shorebirds and waterfowl, and to improvements in estuarine water quality. In addition to direct protection of the watershed hydrologic system (Reeves *et al.*, 1991), primary elements of the restoration and enhancement program within the South Slough watershed include: (a) restoration and recovery of native eelgrass beds; (b) restoration of coastal fresh and salt water wetlands; (c) re-creation of in-stream habitat complexity and winter refuges for juvenile fish; (d) re-establishment of diverse riparian vegetation and upland forests; (e) abandonment of unused roadways to control runoff, erosion, and sedimentation, and (f) restoration of native oyster beds. These elements of the integrated South Slough watershed restoration program are designed to be undertaken on a large spatial scale and within key habitats in order to make measurable advancements toward recovery of the South Slough land-margin ecosystem. Restoration elements include both active and passive remedial steps as well as a series of enhancement projects that focus on specific problem areas within the South Slough NERR.

5.3.2.a Restoration and Recovery of Native Eelgrass

Empirical studies conducted within the South Slough NERR demonstrate that commercial cultivation of Pacific oysters (*Crassostrea gigas*) can have a negative impact on beds of native eelgrass (*Zostera marina*; Carlton *et al.*, 1991; Pregnall, 1993; Everett *et al.*, 1995; Rumrill and Christy, 1996). Similar findings have been reported for other Pacific northwest estuaries (Waddell, 1964; Trianni, 1995; Griffin, 1997; Shreffler *et al.*, 1999; Rumrill and Poulton, 2004). Given the incongruous ecological relationship between oysters and eelgrass, additional studies were conducted within the South Slough NERR to investigate potential eelgrass restoration techniques and rates of eelgrass recovery following removal of oysters. Pregnall (1993) harvested about 780 stakes and 4,700 oysters from a series of four experimental oyster cultivation plots. Eelgrass was transplanted into two plots and the remaining two plots were left to revegetate naturally. Recovery of eelgrass was monitored in all of the experimental plots over a period of two years.

Several different transplant techniques have been evaluated (Fonseca *et al.*, 1982; 1998), and eelgrass plants from high current areas generally exhibit superior growth rates (Fonseca *et al.*, 1979). In the Sough Slough, donor eelgrass plants were harvested from the southwestern tip of Valino Island, directly across the tidal channel from the planting site. Sod plugs were collected from the donor site and included the entire shoot-root-rhizome complex.

After a period of five months, densities of eelgrass shoots remained low in both the transplant and natural recovery plots in comparison to the undisturbed control plots. Recovery of eelgrass plants, however, occurred at a faster rate in the transplant plots (Pregnall, 1993). A direct correlation exists between initial shoot density and rate of eelgrass recovery following oyster removal: plots with initially high densities of eelgrass recover more rapidly than plots with low densities of eelgrass. Vegetative propagation from the surrounding eelgrass beds was largely responsible for eelgrass recovery rather than recruitment from seeds. After a period of one year the density of eelgrass plants was not significantly different between the transplant, natural recovery, and control plots, although eelgrass spatial cover was visibly lower in the sites that had experienced oyster culture. Recovery of eelgrass plants appeared to be complete after two years (Rumrill, pers. observations).

5.3.2.b Restoration of Tidal Wetlands: Winchester Tidelands Restoration Project

A phased recovery strategy was initiated in 1996 to experimentally re-establish tidal hydrology and accelerate recovery of salt marsh vegetation communities and other ecological attributes within a series of neglected agricultural lands in the Winchester Tidelands Restoration Project area of the South Slough NERR (Rumrill and Cornu, 1995). The 30 ha Winchester tidelands area historically consisted of estuarine channels, mudflats, and salt marshes. The majority of these tidal wetlands were removed from tidal circulation around the turn of the century by construction of earth dikes. Linear drainage channels and tidegates were installed by the early settlers to convert the wetlands for agricultural purposes, livestock grazing, and crop production. The original tidal creeks were largely obliterated. These alterations of the tidal marshes decoupled marsh primary production from the estuarine food web and resulted in loss of critical habitat for migrating waterfowl, shorebirds, anadromous fish, invertebrates and mammals.

The long-term effects of tidal exclusion resulted in subsidence of marsh soils within the 5 ha Kunz marsh parcel to an elevation of about +1.5 m North American Vertical Datum NAVD (approximately 60-80 cm below the surface of adjacent mature marshes at +2.2 m NAVD; Figure 5.2). Marsh elevation is critical to habitat function in tidal marshes because elevation determines the inundation period and establishes the timeframe for submergence, sediment accretion, and intertidal zonation of emergent vegetation and other biotic communities. Since the average rate of ambient sediment accretion is generally slow in Pacific northwest estuaries (0.2-0.5 cm yr^{-1} over a period of about 40 yrs; Thom, 1992), natural recovery of the subsided Kunz marsh to the intertidal elevation of a mature sedge marsh was expected to take 150-300 years or longer.

A prescriptive restoration plan was developed for the subsided Kunz marsh that included re-establishment of tidal hydrology, natural recruitment and recovery of emergent marsh vegetation, and the independent development of subsidiary tidal creeks. Earth materials contained within the levee were redistributed by heavy machinery in 1996 into a series of five experimental cells (Cell 1: high marsh +2.2 m NAVD; Cell 2: mid marsh +1.8 m; Cells 3 & 4: low marsh +1.5 m; Cell 5: +1.5 m passive restoration of marsh habitat). The experimental marsh cells were separated by temporary fences that support curtains of geotextile fabric, and each cell is inundated and drained by tidal waters to encourage independent formation of subsidiary tidal channels (Figure 5.2).

Recovery of structural attributes has been monitored within the experimental Kunz marsh cells beginning in 1997 (Cornu and Sadro, 2002). Measurements have been collected along permanent transect lines for several parameters including sediment accretion and elevational changes in the

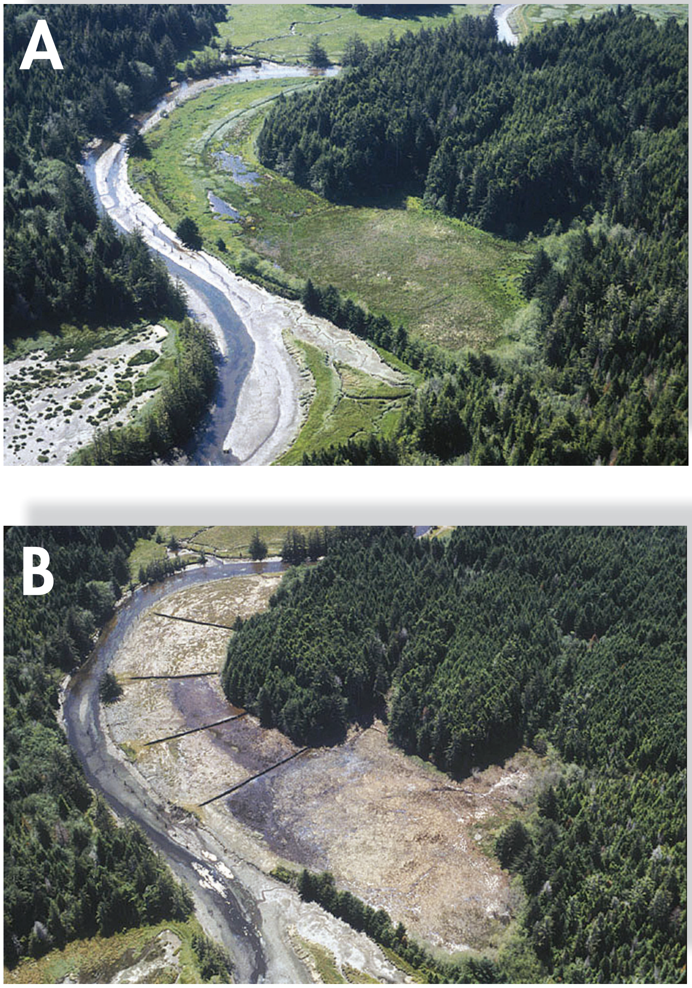


Figure 5.2. Low altitude oblique air photos of the Kunz marsh element (*ca.* 4.86 ha) of the Winchester Tidelands Restoration Project, South Slough NERR, OR. A) Kunz marsh (1991) prior to removal of an earth dike and tidegate. Note presence of linear drainage ditch and freshwater vegetation within the subsided non-tidal wetland. B) Kunz marsh (1997) one year after restoration activities to remove the dike, re-establish hydrological connection with Winchester Creek tidal channel, and redistribute the dike material into five research cells to correct for subsidence.

marsh surface, independent evolution of the tidal creeks, and development of emergent marsh communities and assemblages of invertebrates and fish. Topographic profiles of the experimental marsh cells revealed that annual sediment accretion was highly variable over 1999-2000 (Cell 1: +0.6 cm; Cell 2: +2.0 cm; Cell 3: +0.5 cm; Cell 4: +3.0 cm). The marsh surface experienced an overall decrease in elevation due to settlement and compaction of the unconsolidated subsurface sediments. As expected, development of the subsidiary tidal channels was rapid in the low elevation cells where the flux of tidal waters is high, and retarded in the higher elevation cells where tidal flux is low.

Colonization of emergent salt marsh plants was directly correlated with elevation of the experimental salt marshes. Recovery of species richness and spatial cover was rapid within the high marsh cell, intermediate in the mid marsh cell, and substantially slower in the low marsh cells (Figure 5.3). Conversely, habitat utilization by fish has been greatest within the lowest marsh cells. Results from the experimental salt marshes indicate that management of tidal wetland hydrology by physical manipulation of marsh surface elevations results in a temporal gradient in the recovery of marsh structural attributes. High intertidal marsh elevations favor rapid development of emergent vegetation while lower marsh elevations foster development of tidal creeks and provide habitat for fish and invertebrates.

5.3.2.c Increased Habitat Complexity of Degraded Streams

Several intermittent creeks and perennial streambeds located within the South Slough NERR have been degraded by the historic addition of a heavy overburden of sediments. Removal of timber from the steep hills contributed to erosion of topsoil, and fallen logs were transported by skidding directly along creek bottoms. Moreover, many of the streams historically meandered slowly through densely vegetated freshwater marsh areas before they co-mingled with tidal waters of the South Slough estuary. These meandering streams were straightened and channelized to drain pastures and facilitate growth of agricultural crops. Alteration of the streambeds resulted in significant changes to riparian communities, and to large-scale modifications of the natural hydrological regime. Historic alteration of the streambeds and riparian areas also contributed to decreases in habitat complexity, changes in aquatic invertebrate communities, and reductions in native populations of coho salmon, cutthroat trout, and steelhead.

Dalton Creek is located in the southern region of the South Slough NERR and provides an example of a small perennial coastal stream that was historically altered by removal of timber and promotion of drainage for pastures and agriculture. Restoration of Dalton Creek was undertaken in 1994-98 in a series of deliberate steps to: (a) reintroduce large woody debris (LWD) in the form of fallen trees and large branches into the stream channels to provide winter habitat for anadromous fish, (b) install wood diversionary structures to revitalize lateral hydrodynamic energies and encourage formation of scour pools and channel meanders, (c) elevate the water table to encourage formation of hydric soils, and (d) enhance species composition and diversity of streamside vegetation. These goals were met by installation of several log structures, and LWD that promoted formation of lateral channel meanders and scour pools immediately downstream. The diversionary structures also created pools that accumulated leaf litter and aquatic insects. These pools were used as winter habitat by coho salmon, coastal cutthroat trout, and prickly sculpins. Water held in pools by the log structures and LWD saturated the soft streambank sediments and hydrated the surrounding soils. Groundwater wells were installed in the Dalton Creek marsh to allow future measurements of water table elevation. A variety of native ferns, hemlocks, and alders were planted along the riparian stream banks.

Dalton Creek was historically straightened and channelized along the final section until it emptied into the Winchester Creek tidal channel through a wooden tidegate. Enhancement of Dalton Creek included conversion of the linear drainage ditch into a meandering tidal channel (Figure 5.4). A sinuosity ratio of 2.4:1 (curved length:straight length) was derived from air photos and *in situ* field measurements within several unaltered tidal creeks, and the new creek mouth was relocated about 85 m northward to reflect the prominent geomorphic pattern of the tidal basin. The course of the new meandering channel was determined and subsurface explosives were used to blast a new channel from the existing marsh sediments. Follow-up work was completed with a backhoe to replace vegetation along the banks of the meandering channel. Coho salmon fry were observed within the new channel within 6 months,

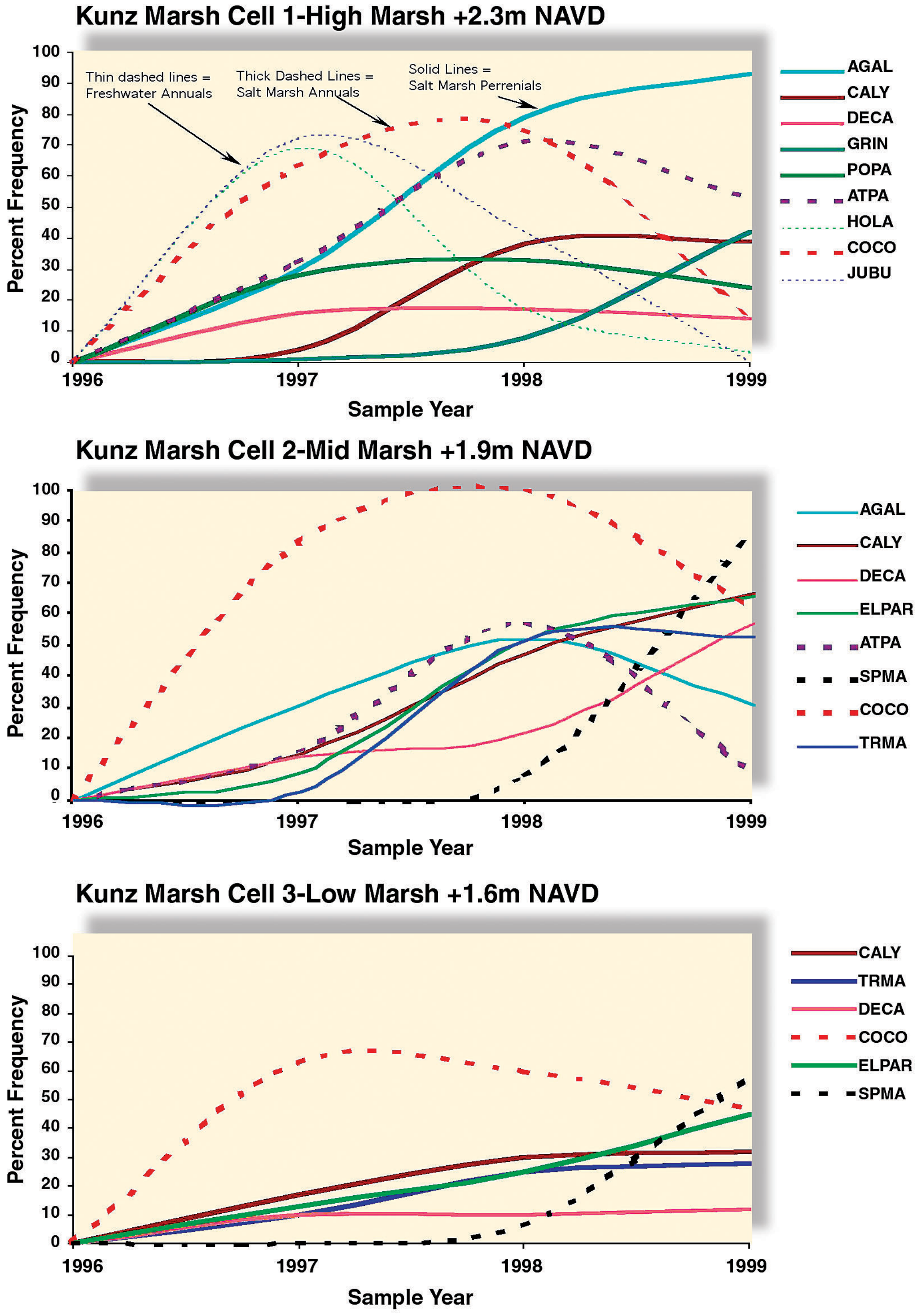
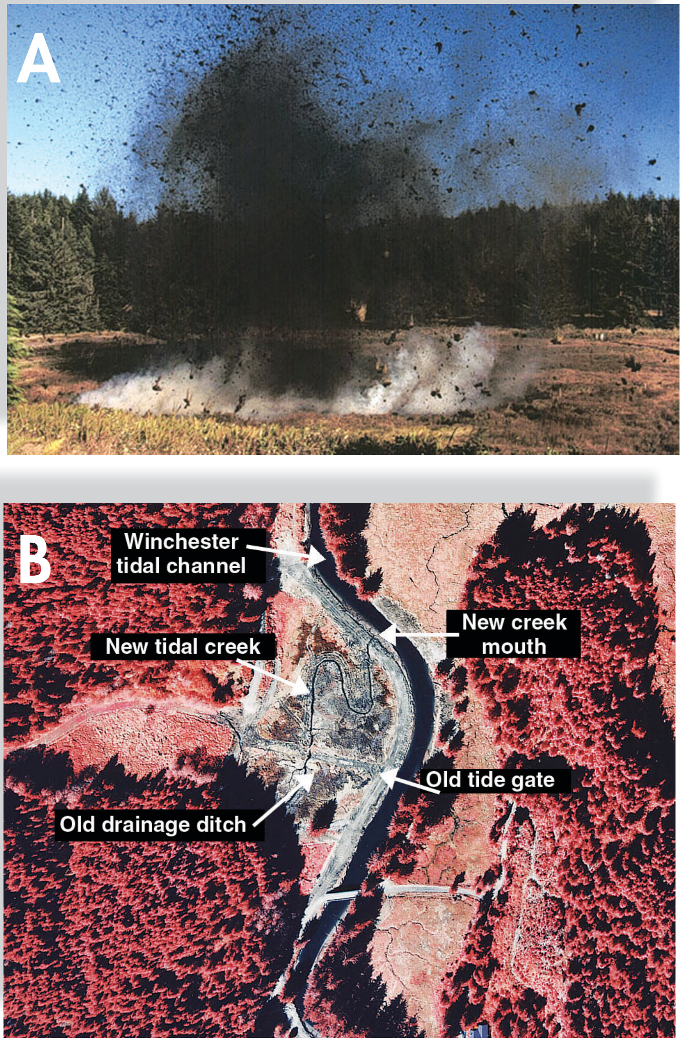


Figure 5.3. Recovery trajectories for emergent salt marsh vegetation communities at different intertidal elevations within the Kunz experimental restoration marsh, South Slough NERR, OR from Cornu and Sadro, 2002; see Figure 3.47 for description of plant codes.



5.4. Creation of a new meandering tidal creek within the Dalton marsh, South Slough NERR, OR. A) Detonation of sub-surface explosives along the course of the new tidal creek bed (1998). B) Elimination of the old linear drainage ditch and re-establishment of hydrologic connection with the Winchester tidal channel through the new tidal creek (color IR air photo, 1999).

and the banks of the new tidal creek were largely vegetated within one year.

5.3.2.d Re-establishment of Native Coastal Forest

The Hidden Creek sub-basin contains a steep coastal forest that was historically managed for timber production prior to designation of the South Slough NERR. Old-growth conifers, primarily Sitka spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*), were harvested from hillsides and riparian areas along Hidden Creek during the early 1900's. The hillsides were replanted primarily with Douglas-fir, and second-growth trees were harvested in 1974. Recovery of native conifers and deciduous trees has been retarded in these 20 yr old clear-cuts by growth of dense understory brush, including salal, salmonberry (*Rubus spectabilis*), and red huckleberry (*Vaccinium parvifolium*). Significant numbers of conifer seedlings and established trees were discovered in the thick undergrowth during site-preparation surveys completed in 1993.

The Hidden Creek restoration project began in 1994 to initiate re-establishment of diverse native forest communities throughout the riparian area and along sections of a popular hiking trail. Restoration activities included site scarification (manual removal of brush to a height 7-15 cm above ground) of 1.7 ha of hillsides and planting of a total of 1,500 trees including 500 Douglas-fir, 350 Sitka spruce, 350 redalder, 100 shore pine, 100 western hemlock, 66 Pacific dogwood (*Cornus nuttalii*), 30 western redcedar, and four big-leaf maple (*Acer macrophyllum*). Locally adapted stock trees consisted of mixed-age seedlings and saplings. Dense brush was removed by extensive site scarification, and the newly planted trees were tagged and equipped with support stakes and degradable tubes to defend against browsers (black-tailed deer *Odocoileus hemionus* and mountain beaver *Aplodontia rufa*).

At a second project site, commercially planted trees (mostly second-growth Douglas-fir) were harvested from the Cox Canyon parcel in 1990. The steep hillsides of Cox Canyon were erroneously zoned for agriculture and revegetated with grass seed by the previous owner. South Slough NERR replanted diverse stands of native trees on a 17.3 ha clear-cut parcel within Cox Canyon in 1996. Lower regions of Cox Canyon were acquired by the South Slough NERR, and the hillsides and riparian areas have developed thick understory vegetation that will require burning, extensive site scarification, and manual release of existing trees and seedlings.

5.3.2.e Abandonment of Unused Roadways and Buildings

The South Slough watershed contains a myriad of paved, gravel, and dirt roads in excess of 2 km of roads per km^2. Some of the existing roadways provide routine access to private residential areas north of the South Slough NERR and infrequent access to commercial and public stands of timber south of the Reserve. In contrast, the majority of old roads located within the administrative boundaries of the 1,934 ha South Slough NERR have been largely abandoned. Passive recovery and recruitment of western hemlock (*Tsuga heterophylla*) and red alder (*Alnus rubra*) has been vigorous over the past 20 years, and shore pine (*Pinus contorta*), evergreen huckleberry (*Vaccinium ovatum*), and salal (*Gaultheria shallon*) have colonized the steep gravel and sandstone roadways. Passive recovery of the abandoned roads has direct benefits to the adjacent hillsides, reduces erosion, and makes it difficult to gain access to remote regions of the Reserve. In severe cases, water bars and drainage diversions were constructed to control the formation of erosion gullies, and geotextile landscape cloth was applied to barren roadcuts to promote recovery of native vegetation. Several additional roads will be decommissioned in association with future restoration and enhancement activities. In addition, several older contemporary residential structures and outbuildings have been dismantled and their vestiges of human occupation removed from the landscape.

5.3.3 Future Restoration Needs

The active steps needed to facilitate restoration of salt marshes are essentially complete within the South Slough NERR. Principals of self-design have been incorporated into the restoration planning process to ensure that the project marsh sites are on a reasonable trajectory for recovery of lost structural attributes and ecological functions. Monitoring efforts will continue to assess changes in the status of habitats and communities. Future progress must be made, however, with restoration and enhancement of the degraded riparian areas, streambeds, and upland forests.

Beds of native Olympia oysters (*Ostrea conchaphila*) were historically abundant in the Coos estuary and South Slough where they were utilized extensively as a food source by the indigenous people. Beds of *O. conchaphila* became locally extinct prior to written history due to basin-wide changes in sedimentation. Since that time, aquatic estuarine habitats within Coos Bay have been degraded by the cumulative effects of sedimentation, bark decay, deposition of dredge spoils, diking, filling, domestic and industrial pollution, and by the colonization by non-indigenous aquatic species. Despite these changes, water column and sediment conditions have improved considerably over the past decades within the tidal basin to the point where they are now conducive to the recovery of native oysters. Consequently, discontinuous populations of *O. conchaphila* have become re-established in the Coos estuary over the past two decades in the low intertidal and shallow subtidal zone. Recovery of native oyster beds will provide ecological benefits to the estuarine tidal basin because the living oyster beds filter the water column and serve as habitat for diverse communities of invertebrates and fish. Future restoration activities will be initiated to investigate the potential to restore self-sustaining populations of *Ostrea conchaphila* in the South Slough estuary. In particular, the efforts will be focused on: (a) investigating the genetic identity of potential brood stock sources, (b) assessment of oyster survivorship, growth, and reproduction, and (3) determination of the ecological interactions between transplanted oysters and established beds of native eelgrass (*Zostera marina*).

Significant restoration and enhancement of the upland forest habitats is needed within large regions of the South Slough NERR. Thinning of existing trees and other manipulations of stand density and species composition are active steps that can be taken to facilitate future development of late seral forest stands. Sheridan (2001) estimated that over 289 ha of commercially-planted forest stands should be thinned within seven specific management areas located within the administrative boundaries of the Reserve. An additional 90 ha within four management areas should be treated to alleviate competition between saplings and understory brush, and to release older trees from dense brushy environments.

In virtually all coastal regions of the United States, natural resource planning agencies face continuing difficulties with development of consistent criteria for the design and evaluation of restoration projects within coastal watersheds. Isolated, single-system restoration approaches have proven insufficient to ensure adequate recovery of critical habitat functions (Zedler and Nyden, 1995; Thom, 1997). Future activities undertaken to restore entire coastal watershed sub-basins in the South Slough NERR, including native stands of diverse conifers and hardwood forests, runs of anadromous fish, shellfish beds, and tidal wetland habitats, are typical of landscape-level recovery efforts now under consideration or underway throughout the Pacific northwest bioregion. Our efforts to restore lost habitat functions and values, however, are hindered by an incomplete understanding of the essential ecosystem components, fundamental energetic processes, interspecific interactions, and feedback mechanisms inherent to the sustained health of coastal watershed ecosystems.

5.4 Anthropogenic Stressors and Future Research Needs

Tidally-influenced habitats within the South Slough estuary and NERR are exposed to a series of chronic and episodic anthropogenic stressors. These primary environmental stressors vary with regard to their long-term impacts on estuarine ecosystem health, and include: (a) large-scale alteration and loss of tidal wetland habitats, (b) disturbance of the watershed by logging operations, (c) disturbance of the estuary mouth by dredging, and the redistribution of suspended sediments, (d) pulsed inputs of suspended organic materials and nutrients from fish processing plants, (e) storm-mediated inputs of fecal coliform bacteria, (f) habitat alteration and community disturbance associated with commercial mariculture of oysters, and (g) chronic / episodic invasions by non-indigenous species.

Research activities undertaken by the South Slough NERR are designed to meet four broad goals:

- Provide opportunities for members of the public, private industry, agency investigators, university faculty, graduate students, and undergraduate students to make significant contributions to our understanding of dynamic change within nearshore and estuarine systems;
- Support use of the South Slough NERR as a natural laboratory or benchmark to assess the magnitude and extent of change in the Coos estuary and other estuarine ecosystems located throughout the lower Columbia bioregion;
- Encourage and assist in the development of an interdisciplinary, science-based, multi-agency approach to ecosystem management within the Coos estuary and other estuarine systems; and
- Improve the availability of technical research information as a basis for more informed coastal management decisions throughout the lower Columbia bioregion.

Future research investigations needed within the South Slough NERR are encompassed by three primary themes: (1) investigation of links between land-margin ecosystem elements, (2) estuarine ecology and assessments of functional biotic diversity, and (3) evaluation of the effects of human disturbance.

5.4.1 Investigation of Links between Land-Margin Ecosystem Elements

Research carried out under this theme can address the general question:

What are the fundamental transfer mechanisms that provide material, bioenergetic, and life-history linkages among the diverse upland, estuarine, and marine components of the South Slough ecosystem?

Examples of specific research projects that focus on links between land-margin ecosystem elements include:

- Material transfer links among nearshore, estuarine, and coastal upland habitats
- Relationships between levels of fecal coliform bacteria, contamination of estuarine shellfish, and land-use activities in adjacent upland habitats
- Assessment of sediment transport mechanisms, deposition, and erosion between upland sources and the estuarine tidal basin
- Tidal forcing of salinity regimes, hydrological circulation, and mechanics of advective tidal flux within South Slough and the Coos estuary
- Reciprocal transport of drift algae and uprooted eelgrass in estuarine and marine environments
- Comparative reliance upon marine, estuarine, and upland habitat sites by marine birds
- Oceanic forcing of invertebrate larval supplies and recruitment into estuarine soft-sediment habitats
- Formation, persistence, and ecological role of bull kelp, *Nereocystis leutkeana*, in estuarine tidal channels
- Transport, fate, and role of large wood in estuarine tideflats and salt marshes
- Larval dispersal patterns, transport mechanisms and advective movement within and among estuaries

5.4.2 Estuarine Ecology and Assessments of Functional Biotic Diversity

Research carried out under this theme can address the general question:

What are the principal biotic components of species assemblages and communities within the South Slough estuary, and to what extent are ecological relationships among diverse groups of organisms determined by top-down processes, bottom-up mechanisms, or environmental stress?

Examples of research projects that focus on estuarine ecology and functional biotic diversity within the South Slough NERR include:

- Assessment of genetic diversity among estuarine organisms
- Development of reliable metrics for species richness, diversity, and abundance across diverse estuarine habitats
- Spatial extent and distribution of critical estuarine habitats for sensitive species
- Quantitative comparison of primary production within the estuarine water column and by microphytobenthos
- Microbial ecology within tideflats, eelgrass beds, and salt marshes
- Biological interactions and ecological relationships among estuarine and marine invertebrates
- Role of predation by shorebirds and waterfowl on populations of estuarine invertebrates
- Extent and distribution of non-indigenous aquatic species within the riverine, mesohaline, marine-dominated, and marine regions of the South Slough estuary
- Ecological consequences of invasion by Japanese eelgrass, *Zostera japonica*
- Intrinsic life-history attributes of estuarine non-indigenous species
- Development of an early warning system to detect arrival by new non-indigenous species
- Control of estuarine communities by top-down (predation and competition) versus bottom-up (nutrients and productivity) processes
- Ecological impacts of episodic storm events and disturbance on the formation and persistence of estuarine communities within riverine and mesohaline regions of the South Slough
- Seasonal dynamics, vegetative growth and development of canopy structure within eelgrass beds, *Zostera marina*
- Distribution and abundance of larval and juvenile fish within estuarine channels
- Ecological role of open tideflat habitats for juvenile salmonids
- Conservation biology and the design of functional estuarine refugia
- Determination of the extent of oceanic forcing, El Niño / La Niña oscillations, and the longer-term ocean regime shift on the composition and structure of estuarine communities
- Anticipated and realized effects of regional climate change on composition, abundance, and distribution of estuarine communities

5.4.3 Evaluation of the Effects of Human Disturbance

Research carried out under this theme can address the general question:

What are the primary ecological impacts of chronic anthropogenic disturbance and human-mediated stressors on biotic diversity, populations, communities, and habitat components within the South Slough watershed and estuary?

Examples of applied research projects that focus on evaluation of the effects of human disturbance on the South Slough NERR and other estuaries include:

- Analysis of input vectors that facilitate introduction of non-indigenous species into the South Slough estuary
- Non-point source pollution and discharge into estuarine tidal creeks
- Ecological consequences of oil spills and other hazardous material discharges in the estuarine environment
- Effects of upstream forest practices on estuarine habitats and communities
- Ecological role of commercial oyster cultivation on native eelgrass, sediments, invertebrates, and fish

- Effects of freshwater withdrawals on community dynamics in estuarine tidal channels
- Ecological influence of seafood processing wastewater within tidal channels
- Long-term effects of landfill runoff on estuarine tidelands
- Influence of docks and marinas on migratory behavior of anadromous fish
- Ecological assessment of the habitat values of diked wetlands
- Experimental evaluation of restoration and enhancement techniques for tidal wetlands
- Empirical assessment of biological and economic advantages during active and passive restoration of degraded estuarine habitats
- Characterization of site-specific performance standards for natural and historically-altered tidal wetlands
- Economic valuation of estuarine habitats and ecological services

5.5 Monitoring of Estuarine Water Quality, Weather, and Biotic Communities

Monitoring activities are conducted within the South Slough NERR in an iterative and/or continuous process that is focused on fundamental characterization of the estuarine environment and to address specific scientific questions and management needs. Monitoring programs are an integral component of the adaptive coastal and estuarine ecosystem management approach, and should be designed to determine whether management actions produce essential information and place the ecosystem on a trajectory toward desired future conditions.

5.5.1 Estuarine Water Quality Parameters

A series of long-term monitoring stations have been deployed along the estuarine gradient of the South Slough in order to collect essential baseline information and to improve our understanding of tidal dynamics and watershed inputs within a drowned river-mouth estuary that is representative of the lower Columbia biogeographic region. These monitoring stations are operated as part of the NERR Systemwide Monitoring Program (SWMP). In particular, the South Slough NERR – SWMP stations collect continuous information to address three primary topics: (a) short-term variability and long-term changes in estuarine water parameters within different regions of the South Slough (*i.e.*, localized impacts of seasonal storm events, variability associated with re-establishment of tidal circulation, interannual differences in rainfall, magnitude and influence of El Niño – La Niña events, spatial extent of oceanic and tidal forcing, and long-term changes associated with the Pacific decadal oscillation); (b) verification, calibration, and refinement of an existing two-dimensional water quality model (CE-QUAL) developed to predict the dynamics of coliform bacteria and dispersion of environmental toxins in the South Slough estuary; and (c) collection of fundamental baseline data for future development of a three-dimensional tidal hydrodynamic model for the South Slough and Coos Bay estuaries.

South Slough NERR currently operates four long-term SWMP water quality stations equipped with multiparameter dataloggers within tidal channels of the Reserve. The first monitoring station (SOS-SE) serves as a reference site and is located within the riverine region of the Sengstacken arm at Talbot Creek immediately adjacent to an expanse of natural sedge marsh (*Carex lyngbyei*). The second station (SOS-WI) serves as a management –treatment site and is located within the riverine region of the Winchester arm adjacent to an experimental dike-removal / tidal marsh restoration area (Kunz marsh). The third station (SOS-VA) is located within the marine-dominated middle region of the estuary immediately north of Valino Island, and the fourth station (SOS-CH) is located in marine waters at the mouth of the estuary. All three SWMP water quality stations are affixed to vertical log pilings driven into the tidal channels, and the automated probe arrays operate continuously at a depth of 0.5 m off the bottom where they record estuarine water depth, temperature, conductivity, salinity, pH, dissolved oxygen, turbidity, and fluorescence. These parameters are indicative of general water column conditions and provide a continuous baseline record of ambient environmental variability within the estuarine tidal channels.

5.5.2 Estuarine Bacteria Levels

Monitoring activities are carried out by the South Slough NERR to determine levels of coliform bacteria in the estuarine tidal channels. Counts of total coliform bacteria, *Eschrichia coli*, and fecal coliform bacteria are determined along the estuarine gradient in cooperation with the Oregon Department of Agriculture. Information gathered by the South Slough NERR is supplementary to the statewide program for management of commercial shellfish harvest areas in estuarine tidal basins.

5.5.3 Local Weather Conditions

South Slough NERR operates an automated SWMP meteorological station to provide digital records of local weather conditions, storm events, and rainfall patterns. The meteorological station is located on a 20 m tower near the mouth of the South Slough estuary, and the sensors record wind direction, velocity, air temperature, relative humidity, barometric pressure, and photosynthetically active radiation (PAR).

5.5.4 Spatial Expansion and Nutrients

Spatial expansion of the series of SWMP stations will possibly include establishment of additional automated water quality dataloggers at several representative sites within the greater Coos estuary. Future expansion of the local array of SWMP stations may also include floating deployments to continuously measure characteristics of surface water at several sites within the estuary. Nutrient concentrations within the estuarine water column will also be monitored to determine the extent to which nitrogen levels and chlorophyll are driven by tidal fluctuations, oceanic forcing, and watershed inputs within different regions of the South Slough estuary.

5.5.5. Monitoring of Biotic Communities

Estuarine research and biotic monitoring have traditionally been tightly coupled activities in Pacific northwest estuaries. Understanding of estuarine processes and ecosystem function often depend on the ability to resolve seasonal cycles from annual and longer-term datasets.

In South Slough NERR, annual monitoring of several biotic elements is ongoing and driven by specific questions from outside grant-supported projects. These currently include annual surveys of eelgrass beds (*Zostera marina*) and their associated communities of infaunal invertebrates, semi-annual surveys for invasive species (European green crabs, *Carcinus maenas*), annual assessments of species composition and spatial cover for salt marsh communities, and seasonal surveys of anadromous fish. Future development of the biotic monitoring program within the Reserve should be supported by the NERR SWMP or other federal programs to meet national and regional monitoring needs, and by the State of Oregon to meet statewide and local concerns.

5.6 Development of Estuarine Ecosystem Models

Our current understanding of the environmental driving forces, structural components, and ecological functions of the South Slough estuary is limited to those elements that have received consideration in this site profile. Positive feedback and enhanced information exchange generated by the adaptive management approach will serve to reduce our level of uncertainty, but additional research focused on detailed understanding of estuarine ecosystem processes is critical to gain further insights. Moreover, new approaches to the acquisition of quantitative datasets that describe habitat features and the interspecific interactions among diverse members of estuarine, marine, and coastal communities are needed to make future progress toward realistic ecosystem models. An ecosystem model of the South Slough estuary will have immediate utility and value in the identification of particularly sensitive ecosystem components, and aid understanding of complex physiochemical processes, food webs that span many habitats, and biotic interactions across ecotones.

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