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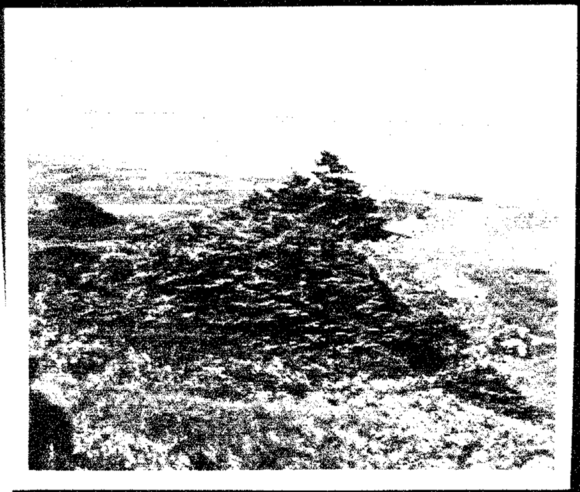
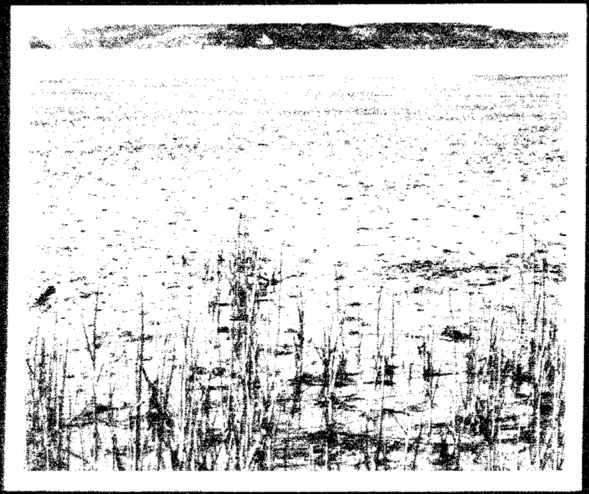
THE ECOLOGY OF TIDAL MARSHES OF THE PACIFIC NORTHWEST COAST:
A Community Profile





Fish and Wildlife Service

U.S. Department of the Interior

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THE ECOLOGY OF TIDAL MARSHES OF THE PACIFIC NORTHWEST COAST: A COMMUNITY PROFILE

by

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PREFACE

This tidal marsh community profile is part of a series of publications concerning coastal habitats. The purpose of this profile is to describe the structure and ecological functions of tidal marshes of the Pacific Northwest coast. This habitat is classified by Cowardin et al. (1979) as occurring in the estuarine system, intertidal subsystem, emergent wetland class, and persistent subclass with a regularly or irregularly flooded water regime. The water chemistry is mixohaline and the soils are mineral or organic.

This profile is a synthesis of scientific information and literature available on various aspects of tidal marsh ecology. There has been much research on some topics and in these areas we will discuss representative data. Little information specifically collected in the geographic region is available on other topics. In the latter cases we have looked to other regions where conditions are similar and have suggested probable conclusions when future research on that topic is conducted in the Pacific Northwest.

The coastal marshes of the region dot the rocky coast. As seen on the cover of this publication, narrow inlets from the sea open to protected bays where marshes form the ecotone between upland and the estuarine habitat. Marsh plants probe the emerging mudflats for a suitable physical and chemical environment. On the upland fringe, where soil aeration increases and salinity drops, these plants lose their competitive advantage to the upland plants. This profile is focused on these estuarine ecotones.

The first two chapters of the text discuss the development of Pacific Northwest coastal wetlands and the physical and chemical environment in which the organisms live. The third chapter treats the biotic communities of tidal marshes. In the Pacific Northwest, there has historically been more emphasis placed on structural aspects of the plant community than on the functional roles for two reasons. First, the diversity and zonation in the Oregon and Washington Marshes are so striking that even ecologists oriented toward mineral cycling and energy flow cannot help but think of indices of similarity, line-point transects, and cluster analyses. Second, and perhaps coincidentally, most of the botanists working in the coastal zone happen to be interested in community structure.

The fourth chapter of the profile focuses on ecological interactions within tidal marshes and between marshes and adjacent systems. There is a paucity of this type of information from the wetlands of Oregon and Washington. Most of the research on these topics in the region is from Canada and describes work relating to salmon in British Columbia. Much of the local information for this section was drawn from our experiences in the marshes of Oregon and our discussions with others working there. Many of the ideas are speculative in nature, and we have carefully tried to point out when the data are inadequate to make definitive statements.

Chapter 5 is a discussion of management practices. It examines both the historical approach and future management efforts built on the current understanding of the role of these discontinuous wetlands in the coastal zone of the Pacific Northwest. The final chapter summarizes the major points about the Pacific Northwest tidal marshes and compares them to those at other sites.

The authority used for plant names in this profile is Hitchcock and Conquist (1973). The authority used for bird names is American Ornithologists' Union (AOU 1982).

The metric system is used throughout this report except in those cases where the convention of the field is to use English units (i.e., soil horizons in inches, fish weights in pounds). For ease in comparison, English equivalents are given for temperature, area, and tidal heights. A table of conversion values is provided for all other cases.

Any questions, comments about, or requests for this publication should be addressed to:

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CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

We are indebted to all those who have worked on the marshlands of the Pacific Northwest to develop the information we have drawn together. We thank all those who reviewed and improved the manuscript, especially Wiley Kitchens, John Cooper, and Penny Herring of the National Coastal Ecosystems Team (NCET) staff.

The photographs were developed and printed by Pam Palinski and Lewis Nelson. Pam Palinski and the NCET graphics group prepared the drawings. Rae Clark typed the various drafts of the manuscript with speed and good cheer.

This report is dedicated to the marriage of the authors which has survived the stresses of producing this document.

CONVERSION FACTORS

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (mt)	2205.0	pounds
metric tons (mt)	1.102	short tons
kilocalories (kcal)	3.968	BTU
Celsius degrees	1.8(C°) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
BTU	0.2520	kilocalories
Fahrenheit degrees	0.5556(F° - 32)	Celsius degrees

CHAPTER 1

PHYSICAL AND CHEMICAL ENVIRONMENT

The boundaries chosen for this profile on the tidal marshes of the Pacific Northwest are the southern border of Oregon and the northern of Washington. Most of the coast (except Puget Sound) is relatively unfeatured, as is all the Pacific coast of the United States. Although the Pacific coast constitutes 22.5% of the general coastline of the country, not including Alaska, it contains only 14.4% of the detailed shoreline (U.S. Geological Survey 1970). The Pacific Northwest comprises 7.9% of the general Pacific coast. The picturesque coast of the region has developed as the result of geological activity which has produced rocky headlands, broad sand dune complexes, sandy pocket beaches, and offshore rocks. Estuaries project inland from the coast where major rivers enter the sea or where embayments are cut off by headlands or baymouth sandbars. The Coast Range was formed from marine sediments and serves to modify the coastal climate as does the California Current. The result is rather uniform coastal temperatures throughout the year.

1.1 REGIONAL CLIMATE AND METEOROLOGY

The Pacific Northwest coast has a mild, mid-latitude west coast marine climate. The maritime influence of the Pacific Ocean provides moderate weather, warming the area in the winter and cooling it in the summer. Also significant in maintaining mild conditions is the protective barrier provided by the Cascade Mountains which guards the coastal area including the Olympic Mountains and the Coast Range against the cold winter and hot summer continental air masses to the east.

During the winter the Aleutian Low, one of the major pressure patterns controlling the Pacific Northwest climate, expands southward over the Gulf of Alaska and the Bering Sea from its usual position over southwest Alaska. Counterclockwise airflow around the low results in winds from the west and southwest. Frontal storms move eastward into the Pacific Northwest, resulting in high precipitation during the winter months. Average annual precipitation along the coast is 180 to 200 cm (70 to 80 inches) per year with 80% of this occurring between October and March. Prolonged periods of light to moderate rain are typical. Snowfall is rare along the coast. Dense cloud cover is common especially during the winter; 80% to 100% cloud cover is reported for half the days of the year. Winds from the south to southwest keep temperatures mild by bringing warmer air from the ocean. Maximum winter temperatures average 3° to 7° C (38° to 45° F) along the Washington coast and in the low teens along the more southern Oregon coast while minimum temperatures range from -2° to 2° C (28° to 36° F) along the Washington coast and near 5° C (41° F) for the Oregon coast (Oceanographic Institute of Washington 1977).

The major pressure pattern controlling Northwest climate during the summer is the North Pacific High which moves from its winter location off the southern California coast to off northern California during the summer. Clockwise airflow around the high results in northwest oceanic winds which keep summer temperatures mild. Coastal upwelling keeps nearshore waters cool and fog often results where the cold water meets warmer offshore waters. Along the Washington coast maximum temperatures range from 17° to 19° C

(63° to 66° F); minimum temperatures average 10° C (50° F). Precipitation during the summer months is light with only 20% of the annual total occurring between April and September (Oceanographic Institute of Washington 1977). A typical annual precipitation pattern is that seen for Tillamook, Oregon, in 1979 (Figure 1).

The climate results in rather benign growth conditions for marsh plants and animals. Hard freezes are not common and ice scouring, which may be important in the development and detritus cycling of New England marshes, is extremely rare. Mild summer temperatures combine with occasional rainfall to keep the interstitial salinity moderate when the lower high tides occur. In Mid-Atlantic, Southeast, Gulf coast, and southern California marshes, evaporation results in hypersaline conditions which lead to reduced plant growth. In the Pacific Northwest the fog and the high frequency of cloud cover reduce light to the point where photosynthesis may be limited for some species. This would be particularly true of plants, such as saltgrass (Distichlis spicata), which have the C4 type of metabolism and can effectively utilize very high light intensity. Other plants such as Pacific silverweed (Potentilla pacifica) have the C3 type of metabolism, and their photosynthetic processes are light saturated at much lower light intensities.

1.2 TIDAL REGIMES AND WATER RELATIONS

The tide along the coast of the Pacific Northwest consists of semidiurnal and diurnal components. The semidiurnal portion occurs approximately every 12 hours while the diurnal component occurs at about 25-hour intervals. These phenomena result in two high tides of unequal amplitude per day: one higher high and one lower high (Oceanographic Institute of Washington 1977). Similarly, two unequal lows occur each day. Figure 2 illustrates a daily tidal height cycle for Astoria, Oregon. Figure 3 illustrates an annual

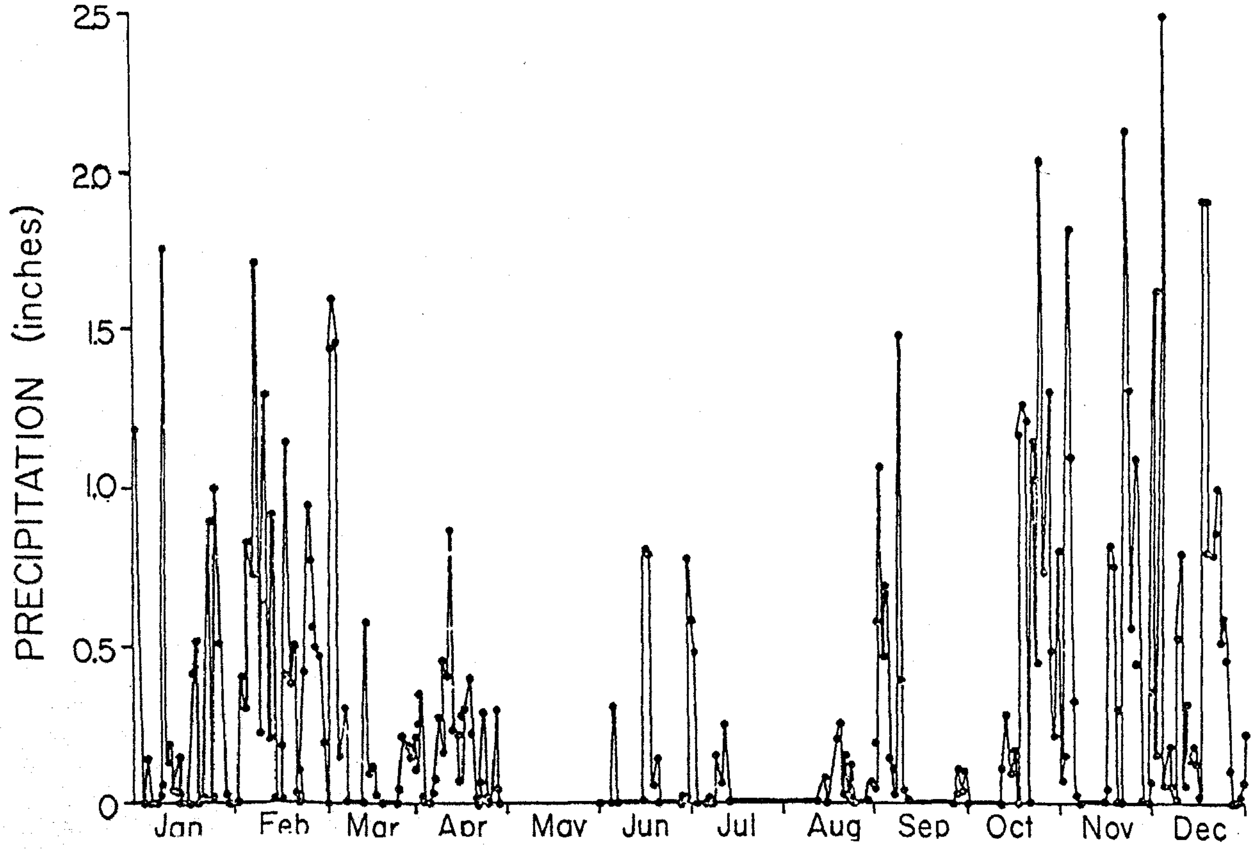

Figure 1. An annual precipitation pattern for coastal Oregon at Tillamook in 1979 (from Seliskar 1981). Although rainfall occurs throughout the year, it is concentrated during periods when the Aleutian low moves southward.

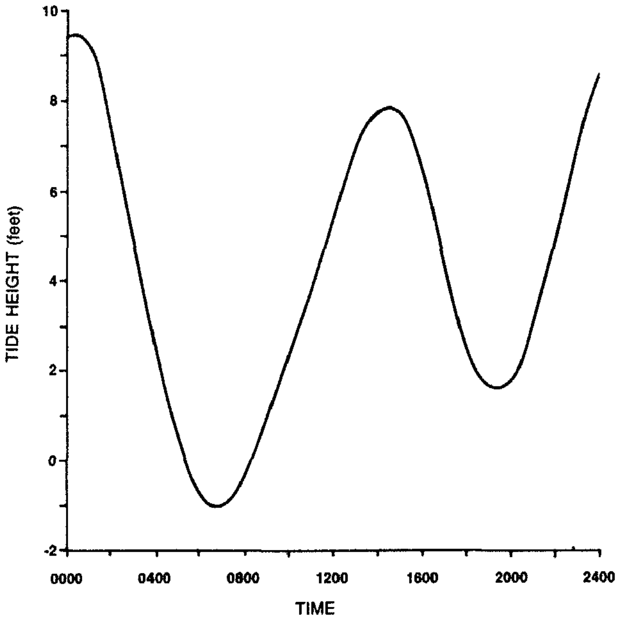

Figure 2. Typical daily tidal curve for Astoria, Oregon (U.S. Department of Commerce 1979).

regime of high tides at Netarts Bay, Oregon. The diurnal range in tidal amplitude varies from zero at the upriver portion of tidal influence to more than 3 meters (10 ft) at certain stations in some estuaries (U.S. Department of Commerce 1979).

The higher tides occur during the fall and winter and result in wetter soils and more frequent input of salts to the intertidal substrates. The combination of changes in atmospheric evaporative power, rainfall, and tidal inundation result in salinities in the lower elevation marsh being highest from July to December (Gallagher and Kibby, unpublished data). In the higher elevation plant stands, salinity was low and more uniform throughout the year. Saturation of the soils with tide and rainwater is most common during the winter. The resultant reduction in soil oxygen comes at a time when the plants are dormant so adverse effects are minimal.

Upwelling is an important feature of waters along the Pacific Northwest coast. During the summer, prevailing winds from the north push surface water offshore allowing deeper, nutrient-rich (due to decomposition processes which occur at depth) water to rise to the surface. Upwelling is most prominent along the southern Oregon and northern California coast. Further northward it is masked on the surface by the Columbia River plume and flow from the Strait of Juan de Fuca. The Columbia River plume produces its own "river-induced upwelling" by pushing surface waters seaward thus allowing nutrients to come close to the surface. Increased nutrients in coastal waters during summer upwellings are important in increasing productivity of the adjacent estuaries; thus nutrients from coastal upwelling eventually bathe the tidal marshes as well (Proctor et al. 1980).

1.2.1 The Estuaries

Tidal marshes are subjected to various salinity and sediment regimes, depending on the type of estuary they border. There are four types of Pacific Northwest estuaries: bar-built, blind, drowned-river, and fjord. Bar-built estuaries are formed by the accumulation of sand along bars which, when connected to shore, restrict water flow to coastal embayments. Netarts Bay, Sand Lake, Grays Harbor, and Willapa Bay are examples of bar-built estuaries (Bottom et al. 1979).

The second type of estuary, the blind estuary, develops from a bar-built type when freshwater or tidal flow is low, usually during the summer, and beach sediments close the mouth of the river. Elk River, Pistol River, Sixes River, and the Winchuck River in Oregon are examples where such closures are common (Bottom et al. 1979).

The third type of estuary is the drowned-river valley. These estuaries were formed upon the rising of sea level at the end of the last ice age and the subsequent flooding of the former river valleys. Coos Bay, Yaquina Bay, Nehalem Bay, and Siletz Bay exemplify this estuary type (Bottom et al. 1979). The Columbia River Estuary, however, is associated with a river that has a clean, stream-cut channel rather than a drowned-river valley (Duxbury 1971). Some estuaries such as

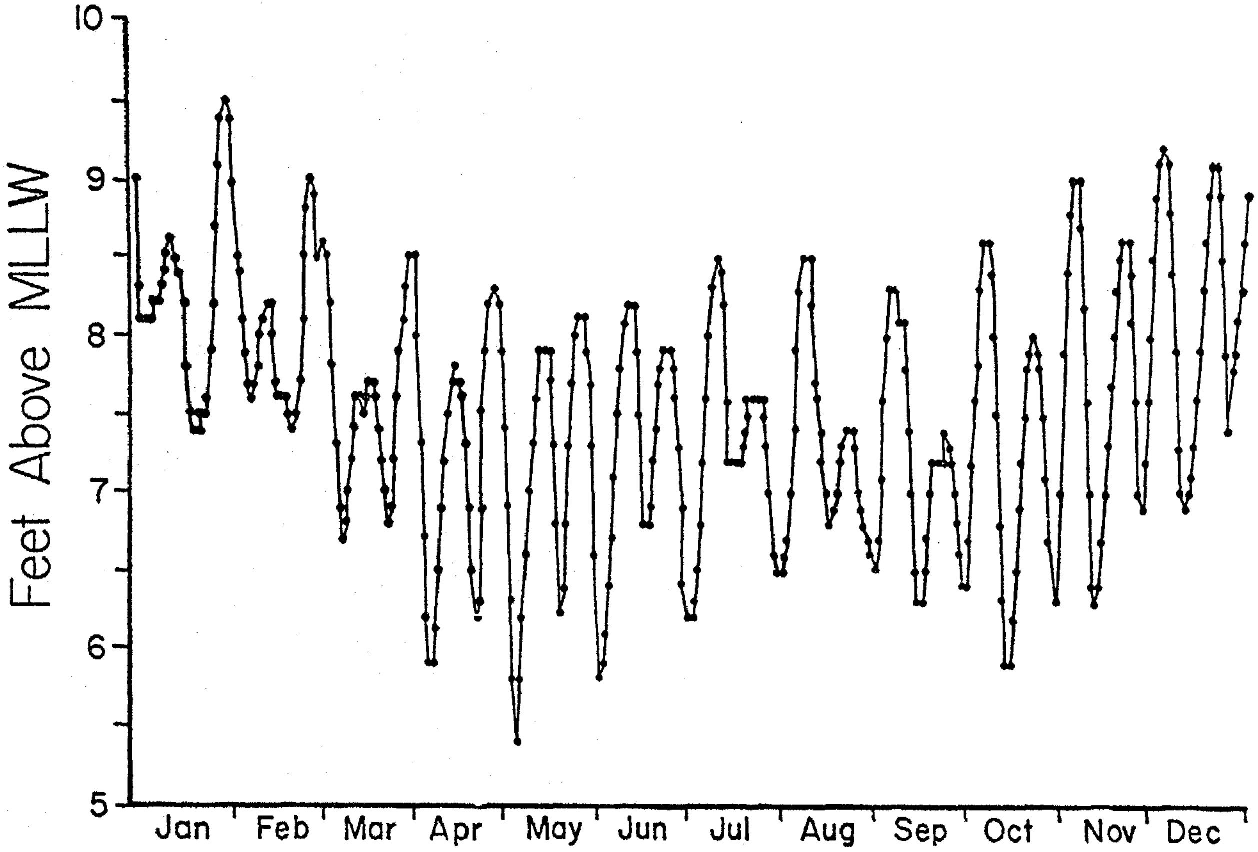

Figure 3. High tides at Netarts Bay, Oregon (from Seliskar 1981). Highest high tides occur fall and winter.

Tillamook Bay show both bar-built and drowned-river characteristics.

Puget Sound, a collection of estuaries of several types, is the most complex of the Pacific Northwest systems. Elements of the Sound are of the fjord type carved out by glaciers (Duxbury 1971). Table 1 lists the Pacific Northwest estuaries and their classification.

1.2.2 River Systems and Runoff

The freshwater runoff patterns into the estuaries of the Pacific Northwest, excluding the Columbia River Estuary, are dependent upon precipitation patterns. Therefore, runoff is high during the rainy, winter season, while in the summer it is significantly less. In the case of the Columbia River, which is the largest source of freshwater entering the Pacific Ocean from Oregon and Washington, runoff peaks in the late because of spring snowmelt. During the summer the freshwater plume moves southwest while in the winter it moves northward (Proctor et al. 1980). Drainage basin areas and mean annual discharge rates for estuaries are included in Table 1.

The amount of freshwater entering the estuarine system is significant to the tidal marshes fringing the estuaries and will influence the species present and the net primary productivity. For example, marsh flora and fauna in the Willapa Bay and Sand Lake marshes are subjected to high salinities due to their small drainage basins and low freshwater input. In estuaries with larger drainage areas such as the Columbia River, there is greater dilution of the salt water. An example of

Table 1. Classification of estuaries of the Pacific Northwest, drainage basin area, and mean annual discharge rates. (Modified from Roden 1967, cited by Proctor et al. 1980; Wilsey and Ham 1974, cited by Bottom et al. 1979; and Percy et al. 1974).

Estuaries	Estuary classification	Drainage basin area (mi^2)	Mean annual discharge rates (10^6 acre ft/yr)
WASHINGTON			
Puget Sound	Fjord	-[a]	-
Quillayute River	Drowned-river	382.0	1.59
Hoh River	Drowned-river	252.8	1.82
Queets River	Drowned-river	443.8	2.99
Quinault River	Drowned-river	264.0	2.02
Grays Harbor	Bar-built		
1) Humptulips River		130.0	0.95
2) Chehalis River		1,813.8	5.63
Willapa Bay	Bar-built		
1) North River		218.8	0.69
2) Willapa River		157.8	0.61
3) Naselle River		89.1	0.38
OREGON			
Columbia River	Stream-cut	255,406.2	184.69
Necanicum River	Drowned-river	87.0	-
Nehalem Bay	Drowned-river	667.6	1.97
Tillamook Bay	Drowned-river	540.0	-
Netarts Bay	Bar-built	14.0	-
Sand Lake	Bar-built	17.0	-
Nestucca Bay	Drowned-river	91.1	0.72
Salmon River	Drowned-river	75.0	-
Siletz Bay	Drowned-river	202.2	1.15
Yaquina Bay	Drowned-river	253.0	-
Alsea Bay	Drowned-river	356.6	1.30
Siuslaw River	Drowned-river	340.4	0.64
Umpqua River	Drowned-river	3,897.6	5.83
Coos Bay	Drowned-river	605.0	-
Coquille River	Drowned-river	756.4	1.79
Sixes River	Blind	129.0	-
Elk River	Blind	94.0	-
Rogue River	Drowned-river	4,939.6	7.72
Pistol River	Blind	106.0	-
Chetco River	Drowned-river	359.0	-

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[a] The symbol (-) indicates no reported values.

the seasonal increase in interstitial soil salinity can be seen in Netarts Bay, an estuary with little freshwater input in the summer. In eight plant stands the salinity rose from an average of 10 parts per thousand (ppt) in April to 22 ppt in July. The change was not uniform over the marsh; little change was noticed at the upper fringe while at lower sites salinity more than doubled (Gallagher and Kibby in prep.).

1.2.3 Tidal Creeks

Estuarine water moves in and out of the salt marshes by way of tidal creeks. According to Eilers (1975), most of the creek systems are of the dendritic type - a major channel with minor branches and sub-branches. In the Nehalem Bay marsh, creeks do not often extend into the marsh area above 2.8 m above mean lower low water (MLLW). The density of marsh creeks is related to elevation, marsh type, and drainage (Eilers 1975). Generally, creek development is most extensive in middle-aged marshes. Due to denser stabilizing vegetation in the upper portions of the marsh creek channel, meandering occurs only in lower marsh areas.

Figure 4 depicts the stream pattern in the marsh at the head of Netarts Bay, Oregon. These extensive channel systems provide access for aquatic organisms which may be using the marsh as a nursery ground and/or feeding site. The stream systems carry detritus from its site of production to the organisms in deeper water. They also bring tidal subsidy to areas of the marsh away from the main estuarine channel. Although the term is incompletely defined and not yet quantified, Odum (1980) proposes that tidal energy subsidizes the coastal marshes. That subsidy may take the form of removing toxic organic materials, carrying oxygen and nutrients to the root zone, diluting salt near the roots, or other undefined work. The sedge in Oregon marshes is more vigorous along the streambanks than is the backmarsh, a phenomenon which may be associated with tidal subsidy (Gallagher and Kibby 1981).

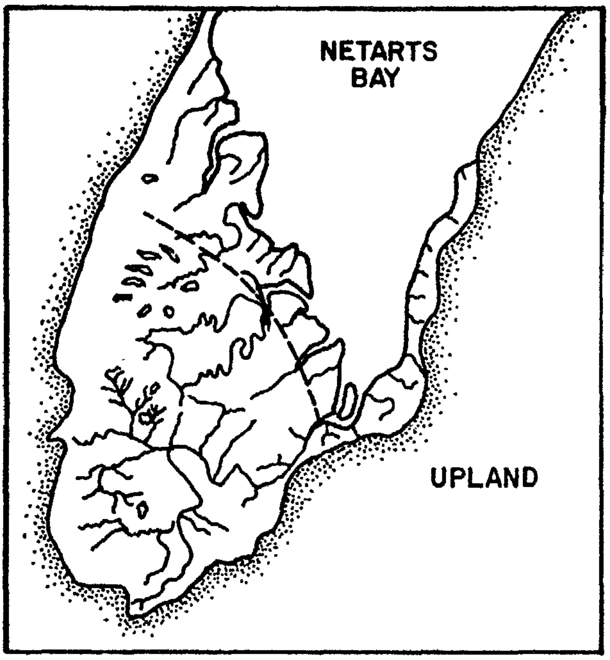

Figure 4. Stream patterns in the marsh at the head of Netarts Bay, Oregon. The dashed line indicates the position of an old dike.

An old dike is indicated by the dotted line in Figure 4, and a number of brackish water pools are seen in the upper reaches of the marsh. Such dikes were placed on many marshes to make them dry enough for pasturing. Tide gates allowed creeks to drain precipitation and upland runoff but blocked incoming tidal water.

1.3 SOILS - SALINITY AND FERTILITY

The physical and chemical environments of Pacific Northwest marsh soils appear to be similar to those in coastal wetlands at similar latitudes on the Atlantic coast. Soils range from sand or silt to peat, depending on the age of the marsh and the type and amount of sediment load in the adjacent rivers. Their salinities likewise depend on the nature of the estuarine system in which they develop and the position of their sites within the estuary. The systems range from those dominated by freshwater from large rivers such as the Columbia to those with primarily oceanic influence. Nutrient input to marsh soils from the ocean is likely greatest during seasonal coastal upwelling. Input from the land is greatest when runoff from the nearby hills is high during rain in the fall, winter, and spring, and during snowmelt in the Cascades in the spring.

Extensive studies have not been made of marsh soils in the Pacific Northwest. Liverman (1982) excavated soil pits along transects from upland to tidal flat at Netarts Bay, Oregon. The soil was composed almost entirely of sand in the upland (dune) and tideflat. Between these two areas lies the tidal marsh. In the middle marsh several soil horizons exist. The surface 0.5 m is a dark greyish-brown sandy loam. Below this is a layer of dark grey clay loam approximately 0.25 m thick. The next half meter consists of dark greyish-brown sand beneath which is a dark grey-blue clay. These descriptions are ecological in nature but would be classified as Entisols by pedologists. Generally marsh soils are classified in either the order Entisol or Histosol. The primarily organic soils are the Histosols, and they are called Sulfihemists in coastal areas where sulfides are produced from the reduction of seawater sulfates. Sulfaquents are recently formed mineral soils (Entisols) common to the salt marsh (Gallagher 1980). Table 2 illustrates a typical profile for a Histosol and an Entisol from the marsh. Although the profiles were described from Atlantic coast marshes, spot checks of characteristics in Pacific Northwest marsh soils indicate that the profiles are similar. There is certainly no evidence that soils developing in similar latitudes with similar types of flooding and salinity regimes would be different on the two coasts. Details of determinations of pH, color, texture, etc., can be found in Breeding et al. (1974), Darmody and Foss (1978), and Gallagher (1980).

Moisture content in salt marsh soils is dependent upon precipitation and frequency of submergence, the latter of which, of course, is related to elevation. Saturated conditions generally exist in lower elevation marshes. Seliskar (1981) measured soil moisture along transects in the salt marsh fringing Netarts Bay, Oregon, using permanently implanted soil moisture tensiometers. Soil moisture tension, a measure of dryness, is highest in soils in the upper marsh (Figure 5). The large drops in tension closely coincide with precipitation data for the area. High tensions develop between storms and spring tides.

Gallagher (1980) described five factors which influence marsh soil salinity: (1) salinity of the flooding estuarine water; (2) tidal elevation; (3) the environmental complex (including temperature, pan evaporation, and rainfall); (4) soil texture (coarser soils are more easily flushed); and (5) specific evapotranspiration rate of the plant species. Soil salinity measured along transects at Netarts Bay, Oregon, decreased from lower to upper marsh (Seliskar 1981; Liverman 1982). The higher salinity at the lower elevations is due to the frequent flooding by the estuarine waters. As one moves landward, flooding of the marsh is less frequent and rainwater dilutes the salts that are present. Salinity may also decline with depth in the marsh. In some sandy marshes low salinity ground water may surface at the interface of the marsh and mudflat. Liverman (1982) found that in the marsh on the Netarts sand spit a lens-shaped freshwater body floats on top of a convex salt groundwater body. The freshwater lens recharges with winter precipitation, but during the summer its level approaches the surface of the salt groundwater. The point of freshwater discharge onto the marsh depends on the depth of the salt groundwater surface.

The supply of nutrients provided by a soil depends, for the most part, upon the texture of the soil. The coarser the substrate, the lower the nutrients. Finer textured salt marsh soils have the highest nutrient content due to their greater cation exchange capacity (Gallagher 1980). Seliskar (1981) found that potassium (K), calcium (Ca), magnesium (Mg), and total nitrogen (total N) were much lower in a transect which consisted totally of sand than in any of the other more silty tran-

Table 2. Description of a typical Sulfihemist (Histosol) and a typical Sulfaquent (Entisol) from coastal marshes. These descriptions were written from Atlantic coast marshes, but checks of salinity, boundaries, pH texture, and structure on Pacific Northwest marsh profiles indicate similar soil descriptions would apply to them. Color designations were obtained using the Munsell soil color chart.

Horizon	Depth (inches)	Color	Texture	Structure consistency	pH	Boundary	Salinity (ppt)
TYPIC SULFIHEMIST							
Oi 1	0-8	10 YR 3/2	Organic, 5% mineral	Massive, non-sticky	6.6	Abrupt, smooth	29.3
Oe 1	0-15	10 YR 2/1	Organic, 10% mineral	Massive, slightly sticky	6.8	Abrupt, smooth	27.1
Oe 2	15-31	5 YR 3/2	Organic, 20% mineral	Massive, slightly sticky	7.0	Abrupt, smooth	27.2
Oe 3	31-42	5 YR 2/2	Organic, 10% mineral	Massive, slightly sticky	6.8	Gradual, smooth	25.6
Oe 4	42-63	5 YR 2/2	Organic, 15% mineral	Massive, slightly sticky	7.0	no boundary	25.4
TYPIC SULFAQUENT							
A 11	0-8	10 YR 3/1	Clay loam	Weak, subangular blocky, sticky	6.9	Gradual, wavy	33
A 12g	8-19	10 YR 3/1	Clay loam	Massive, sticky	7.0	Clear, wavy	36
C 1g	19-33	10 YR 4/1	Clay	Massive, sticky	6.9	Gradual, wavy	38
C 2g	33-50	5 GY 5/1	Clay	Massive, sticky	6.8	Gradual, wavy	39
C 3g	50-60	5 GY 5/1	Silty clay	Massive, sticky	7.2		36

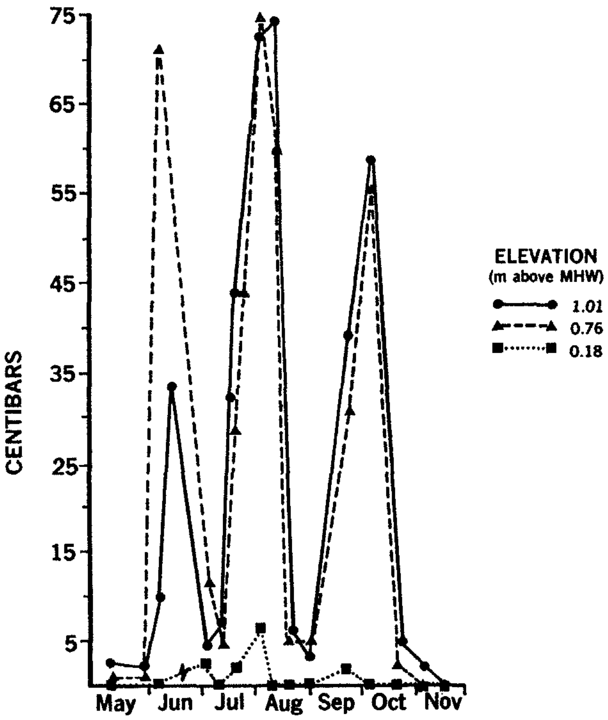

Figure 5. Marsh soil moisture tension during the growing season at Netarts Bay, Oregon, at a depth of 10 cm (modified from Seliskar 1981).

sects. In the sandy site, K, Ca, Mg, and total N values were approximately 200 parts per million (ppm), 1.0 milliequivalents (meq)/100 g, 2.3 meq/100 g, and 0.05%, respectively, while in the siltier areas, the values were approximately 2,000 ppm, 8.0 meq/100 g, 25.0 meq/100 g, and 0.5% for K, Ca, Mg, and total N, respectively.

Marsh soils which are submerged frequently are often anaerobic below a depth of 3 cm. Oxygen is rapidly removed by the decomposition process. As a result, chemicals in these soils generally occur in a reduced state. During anaerobic decomposition, compounds such as sulfides, organic acids, and aldehydes which are often toxic to some organisms may accumulate.

Sedimentation is important in a number of ways in the marsh. Where sea level is rising relative to the land, it provides a mechanism for the plants to maintain their position relative to submergence. Further, it provides a mechanism for elevating mudflats to a height which will support marsh plant growth. Using maps and aerial photographs, Johannessen (1961) calculated the rate of lateral advance of tidal marsh in the Coquille Estuary between 1887 and 1939 and found it to be approximately 70 ft/yr. The rate has decreased since then to about 5 ft/yr. Between 1940 and 1960, the amount of marsh doubled in Kentuck Slough of Coos Bay. Little net change has occurred in the Alsea Estuary although there are areas of advancement and retreatment. Since 1875, marsh advancement has ranged from 0 to 27 ft/yr at Nehalem Bay (Johannessen 1961).

Jefferson (1975) reported accretion rates of 0.5 to 1.7 cm/year in low, silty Oregon marshes. Deposition is uneven between marshes because sediment loads vary from one estuary to another and current velocities vary due to plant density, water volume, and area of spreading. Within a marsh, deposition is usually greatest along the stream banks where the current velocity first slows. Observations by the authors in the Fraser Estuary in British Columbia indicated that almost all the deposition occurs during the spring freshet. Deposits of 5 cm/yr were common. Stumpf (1981) has measured deposition rates in a Delaware salt marsh and found that most of the annual deposition was associated with storm events, not day-to-day inundation. We suspect a few events each year are also resonsible for most deposition in the Pacific Northwest marshes.

CHAPTER 2

MARSH DISTRIBUTION

Steep relief characterizes the terrestrial side of the division between land and sea and extends below the waves. The heavy wave action dominating the exposed shores of the Pacific Northwest coast produces an inhospitable site for marshland development. There are, however, two types of protected havens along this high-energy coastline where marshes develop.

The most common tidal marshland sites are those fringing the borders of rivers which run more or less directly into the Pacific Ocean (Figure 6). The Salmon River Estuary, for example, has extensive fringing marshes. Historically, this type of marsh extended many miles up the rivers, but diking has converted many of the upper river tidal wetlands into pastures. A second setting for wetlands is in the lee of emergent bay-mouth bars which enclose broad river valleys where low energy locations necessary for the development of marshlands occur. Grays Harbor and Willapa Bay, Washington, and Tillamook Bay, Oregon, are examples of the latter type.

2.1 DISTRIBUTION OF TIDAL MARSHES

Jefferson (1975) and Eilers (1975) measured areas of existing salt marsh for 14 Oregon estuaries from aerial photographs and maps (Table 3). Jefferson (1975) stated that in Oregon there was a total of 29 km^2 of undiked salt marsh, excluding the Columbia River.

Salt marshes in the Northwest have been shown to be prograding; Johannessen (1964) found that the Nehalem Bay, Tillamook Bay, Umpqua River, Coos Bay, and Coquille River marshes of Oregon were expanding, but found no such expansion at the Alsea. Eilers (1975) measured progradation of the wetlands at Nehalem Bay at a maximum rate of 2.4 m/year. A possible reason for this accretion is increased riverine sedimentation due to agriculture and logging practices and perhaps erosion brought about by forest fires (Akins and Jefferson 1973). Figure 7 illustrates a marsh-mudflat interface where accretion is elevating a tidal flat and the marsh is expanding seaward.

Even though considerable progradation has taken place in past years, the loss of marsh habitat is still greater than its gain. For example, in the last 100 years 90% of the Coos Bay salt marsh has been destroyed for various purposes including agriculture, industry, and residences. The City of Coos Bay, Oregon, is built on what was once marsh (Hoffnagle and Olson 1974). Sixty percent of the marshland bordering Puget Sound in the early 1800's has been lost to dredge and fill projects, jetties, and marinas. This does not include land loss before the area was first mapped (Meyer 1979). Diking has stopped the natural functioning of more salt marsh than any other type of intrusion. Once it was found that such areas provided productive farmland, most areas of high marsh in Oregon were diked (Jefferson 1975). About 50% of original wetlands of Willapa Bay, Washington, have been diked or filled (U.S. Department of the Interior 1970).

In light of the importance of the salt marshes to coastal ecosystems, marshlands are being reclaimed from agricultural use in some places by breaking the dikes. Mitchell (1981) conducted research on the natural establishment and succession of salt marsh plants into a previ-

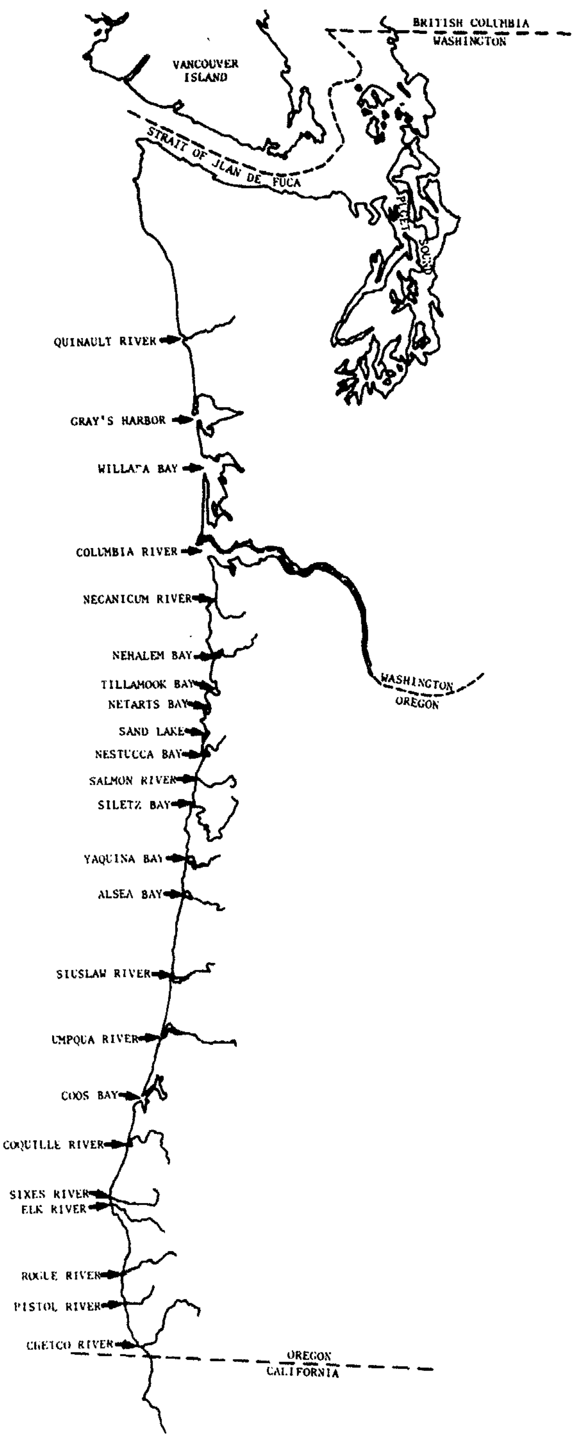

Figure 6. Location of estuaries in Oregon and Washington (U.S. Geological Survey 1970).

Table 3. Areal extent of salt marshes associated with Oregon estuaries (from Jefferson 1975 and Eilers 1975).

	Acres of salt marsh	
	Jefferson (1975)	Eilers (1975)
Columbia River	-[a]	-
Necanicum River	10	30
Nehalem Bay	440	601
Tillamook Bay	902	898
Netarts Bay	161	273
Sand Lake	415	670
Nestucca Bay	203	225
Salmon River	366	184
Siletz Bay	264	360
Yaquina Bay	657	1102
Alsea Bay	561	652
Siuslaw River	761	785
Umpqua River	689	805
Coos Bay	1435	2239
Coquille River	257	393
Sixes River	-	-
Elk River	-	-
Rogue River	12	-
Pistol River	-	-
Chetco River	2	-
TOTAL	7135	9217

[a] The symbol (-) indicates no value reported.

ously diked area on the Salmon River Estuary. Marshes similar to the adjacent natural systems seem to be developing rapidly on these newly flooded areas. Federal action has also been taken to protect wetland environments and is discussed in Chapter 5.

2.2 TYPE OF MARSHES

Akins and Jefferson (1973) describe eight types of tidal marshes in Oregon: (1) low sandy marshes, (2) low silty marshes, (3) sedge marshes, (4) immature high marshes, (5) mature high marshes, (6) bulrush and sedge marshes, (7) intertidal gravel marshes, and (8) diked salt marshes. These marsh types are the result of the selection of marsh plant species which are best adapted to a particular

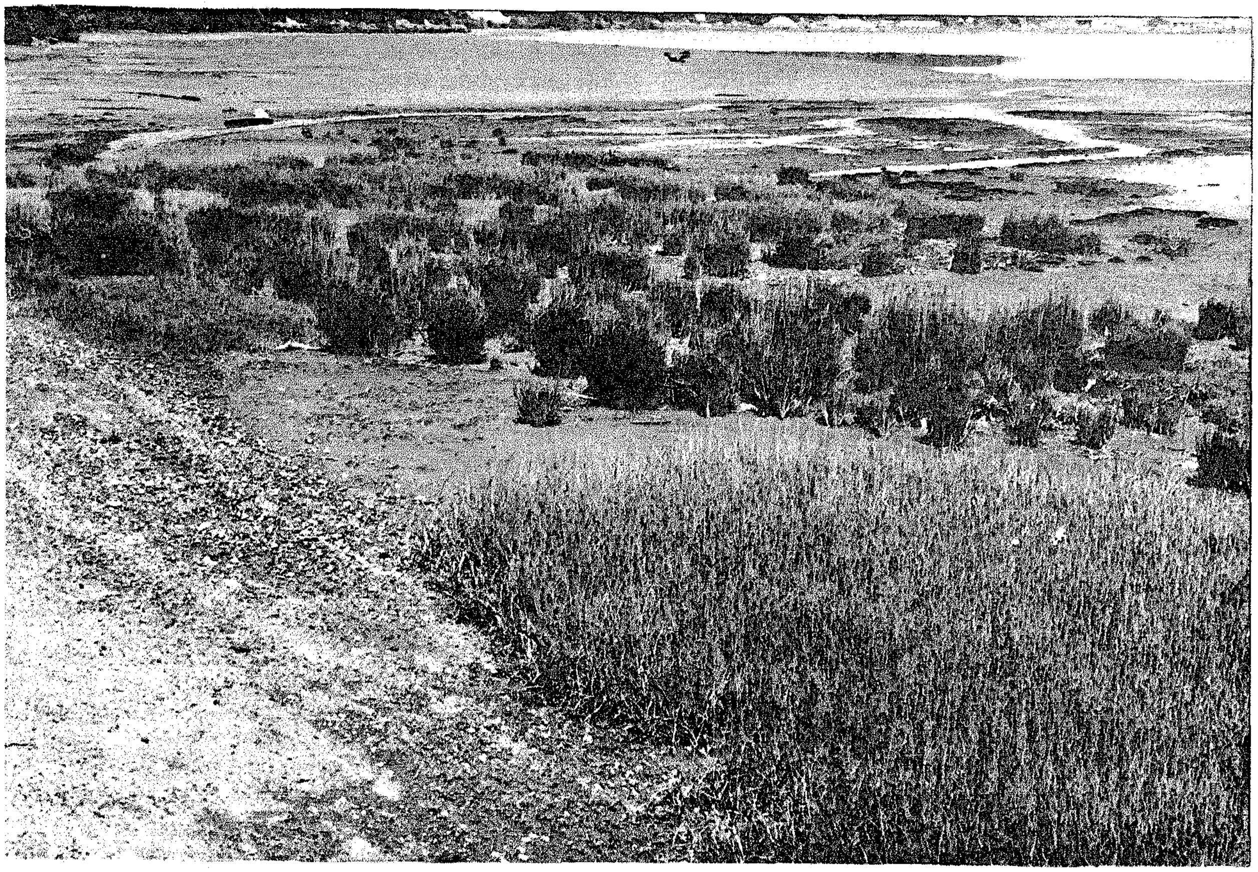

Figure 7. Zone of accretion at the marsh-mudflat interface. A patch of pickleweed is seen in the left foreground and tufts of arrowgrass are invading the mudflat in the center of the photograph.

combination of substrate, estuarine salinity regime, and elevation. The characteristics of the eight marsh types are summarized in Table 4.

Low sandy marshes occur on sandy substrate with a gradual slope, typically on the low-energy side of bay mouth sand spits or as fringing marshes on islands with coarse textured sediments. They are flooded by nearly all high tides and drain diffusely (i.e., there are no tidal creeks) over the marsh surface. Near the tidal flat edge, the vegetation is scattered, but becomes continuous up the slope.

Low silty marshes develop on fine-textured sediments, silt, or mud substrate in low energy parts of estuaries and are relatively flat. These marshes develop in areas of rapid sedimentation and are flooded by nearly all high tides. They have diffuse drainage patterns with some defined channels around clumps of plants, which are discontinuous at the lower elevations as in the low sandy marshes.

Sedge marshes also form on silt and have a nearly level surface. They are often found on island or delta edges with elevations somewhat above the first two marsh types. They are flooded by most high tides and drain via creeks in the higher sedge marshes and diffusely in the lower ones. Soil salinities are often low during spring freshets. Vegetation is continuous and low in diversity.

Immature high marshes are relatively level with some bare depressions and are located on silty substrates. Organic matter accumulation is abundant here as it is in sedge wetlands. Immature high marshes occur above sedge and low sandy marshes, usually at least 40 cm above the tidal flat; often the transition is an abrupt rise. Many of the high tides, especially

Table 4. Characteristics of the eight types of marshes described for Oregon by Akins and Jefferson (1973).

Marsh type	Sub-strate	Relative elevation	Vegetative cover	Drainage	Slope
Low sandy	Sand	Slightly above tideflat	Continuous except near tideflat	Diffuse	Gradual toward upland
Low silty	Silt or clay	As above	As above	Diffuse plus small channels	As above
Sedge	Silt	Slightly above low silty marsh (20-30 cm above tideflat)	Continuous	Deep channels	Nearly level
Immature high	Peat over silt	40 cm or more above tideflat	Continuous	Channels	Nearly level
Mature high	Peat over silt	Slightly above immature high	Continuous but with pans	Deep channels	Nearly level with depression
Bulrush and sedge	Silt or sand	Similar to low silty in brackish to fresh tidal water	Continuous	Diffuse	Nearly level
Intertidal gravel	Gravel and sand	Variable	Sparse	Diffuse	Sloped perhaps steeply
Diked	Peat over silt	As immature or mature high	Continuous	Former channels filled	Nearly level

the higher highs, cover the soil surface. A well-defined system of channels drain and flood these marshes, which have few open areas in the vegetative canopy.

Mature high marshes are level and have developed extensive peaty soils. A dendritic network of steep-sided stream channels circulates water to the soil surface on higher high tides. Shallow saline pools (pans) produce openings in the otherwise continuous sward of vegetation. Salinities fluctuate widely and depend on rainfall, tidal input, and evaporation. These pools may become very saline or even dry when evaporation rates are high and neap tides do not carry water high enough to reach the depressions. Mature high marshes are found a meter or more above the tidal flat.

Bulrush and sedge marshes are low marshes in brackish parts of the estuary. The substrate is silt or sand, and inundation occurs with most high tides. Drainage is diffuse. Vegetation is continuous and its composition is dependent on the salinity.

Intertidal gravel marshes are rare forms which develop on sand and gravel bars near the mouths of relatively high-energy estuaries with large volumes of freshwater. Vegetation is discontinuous and of a type which indicates low salinities. The salt from the tidal water is probably leached by rainwater and freshwater runoff through the coarse substrates.

Diked salt marshes are manmade habitats that develop when the tides are excluded from immature and mature high marshes. Although non-salt marsh plants may invade, the area retains some wetland characteristics due to seepage, high water tables, and perhaps residual salinity. Vegetation is continuous over the marsh surface and the old dendritic stream channel system has collapsed.

In the recent classification system developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979), the tidal marshes of the Pacific Northwest are classified as follows: SYSTEM-estuarine; SUBSYSTEM-intertidal; CLASS-emergent wetland; SUBCLASS-persistent; WATER REGIME-regularly flooded or irregularly flooded; WATER CHEMISTRY-mixohaline (0.5 to 30.0 ppt); and SOIL-mineral or organic. Additional modifiers that pertain to some northwest marshes are diked and artificial (dredge materials).

CHAPTER 3

BIOTIC COMMUNITIES

This chapter describes the communities of organisms in the tidal marshes of the Pacific Northwest. The marsh complex includes the vegetated, relatively flat portions which drain during low tide, the shallow pans which may hold water for months, and the creeks which circulate water throughout some types of marsh. These creeks may be dry during low tide or retain water throughout the tidal cycle. There are a number of macrophytic plant communities, and the species richness within the marshes of a single estuary is often high. Jefferson (1975) has identified approximately 70 species in the salt marshes of the region. The literature on plant species composition and community structure is relatively abundant. The marsh microbial communities on the decaying plant material and in the soil have not been studied in any detail. Faunal components of the system have received more attention because of their economic importance. Extensive species lists of invertebrates, fishes, birds, and mammals have been compiled.

Several aspects of seed-bearing vegetation are important. The first, zonation and species distribution, is of obvious interest relative to marsh types and roles. The second aspect is the upland boundary, which, besides its scientific interest, is assured particular importance because of its role in defining the limits of regulation relative to Section 404 of the Clean Water Act (Public Law 92-500). Because of its importance in wetland management, we will defer the discussion of boundaries until Chapter 5. Topics not dealing with the structure of the plant community, such as productivity, are summarized in Chapter 4, which discusses ecological processes.

The literature on the second group, the autotrophic and heterotrophic microbes, is sparse. In this section it has been necessary to draw on the literature from other regions of the country to provide information on the probable microbial activities in the Pacific Northwest. Although data from other areas are not as good as firsthand studies, they do provide a basis for future research and some insight into the probable role these organisms play in the marshes of Oregon and Washington.

Although the faunal communities are the best described communities in the Pacific Northwest marshes, the foodweb relationships between populations is not very well known. There is, however, a rather extensive Canadian literature from which to draw information about the fishes.

3.1 VEGETATION - ZONATION AND SPECIES DISTRIBUTION

Zonation in marshes of the Pacific Northwest, as in marshes elsewhere, is largely a result of the pattern of tidal inundation. The role of inundation is complex and may involve a multitude of factors including soil salinity, moisture, aeration, and nutrient status. Burg et al. (1976), Disraeli and Fonda (1978) and Ewing (1983), among others, have identified salinity, elevation, and inundation as important factors in controlling community composition. One of the most widely studied effects of inundation is development of the salinity regime to which the plants are exposed. The salinity gradient in the estuarine marshes has vertical, lateral, and linear components.

The vertical gradient extends from the soil surface downward and may be important in determining which part of the root system is functional in water uptake. In the lateral gradient from the mudflat edge to the upland boundary, the higher salinities generally occur in the lower marsh with the upland edge being nearly fresh. Horizontally, salinity decreases from the river mouth to the limit of tidal influence.

Other effects of tidal waters which influence vegetational zonation include aeration of the root zone and nutrient supply. Soil type is also important, and in coarse sandy soils salt is removed from the surface by the rapid percolation of rainwater. Clay soils have low percolation rates, and permeability is decreased further when the cation exchange capacity of the clays becomes saturated with sodium ions. Under these conditions, soil peds break down and the soil structure deteriorates in a massive form, making the movement of air and water through the substrate difficult (Gallagher 1977).

The eight marsh types outlined by Akins and Jefferson (1973) and the typical plant assemblages associated with them are listed in Table 5. Table 6 lists plant species common to Pacific Northwest tidal marshes. In the low sandy marshes of Oregon, the areas closest to the tideflats are dominated by three-square, pickleweed (Figure 8), saltgrass, and alkaligrass (common on the northern part of the Pacific Northwest coast), along with some blue-green algae and _Cladophora_ (a green alga). Saltgrass, seaside plantain (Figure 9), sandspurry, Lyngbye's sedge, and milkwort are common at higher elevations in the low sandy marsh (Jefferson 1975). The parasitic plant dodder is often found growing over saltgrass and pickleweed plants.

Circular patches of arrow-grass (Figure 10) and clumps of pickleweed are common in the low silty marshes, as are scattered spike-rush plants and sandspurry. Possible secondary invaders to these areas are tufted hairgrass and Lyngbye's sedge (Jefferson 1975).

Table 5. Eight Oregon marsh community types and their typical plant species composition (Akins and Jefferson 1973).

Marsh type	Plant species
Low sandy	Pickleweed, three-square, saltgrass, Jaumea, seaside plantain, sandspurry, Lyngbye's sedge, milkwort
Low silty sand spurry	Arrow-grass, spike-rush,
Sedge	Lyngbye's sedge
Immature high	Tufted hairgrass, saltgrass,arrow-grass, pickleweed, Lyngbye's sedge
Mature high	Tufted hairgrass, Baltic rush, creeping bentgrass, gum plant, Pacific silverweed, orache
Bulrush and sedge	Bulrush, Lyngbye's sedge
Intertidal gravel	Spike-rush
Diked	Tufted hairgrass, salt rush, creeping bentgrass, gum plant, Pacific silverweed, orache

The sedge marshes consist almost solely of monospecific stands of Lyngbye's sedge. Extensive sedge marshes are located on the Siletz River delta and the brackish portions of estuaries where the intertidal zone is silty. The tall creekbank plants are seen in Figure 11. In many respects Lyngbye's sedge appears to be a Pacific Northwest analogue of the east coast smooth cordgrass, _Spartina alterniflora_. Lyngbye's sedge grows in

Table 6. Common plant species found in Pacific Northwest tidal marshes. L=low marsh; H=upper marsh.

Common name	Scientific name	Family	Position in the marsh	Notes
Alkaligrass	*Puccinellia pumila*	Graminae	L	Most abundant in muddy areas, also on Atlantic coast
Arrow-grass	*Triglochin maritimum*	Juncaginaceae	L	Often a pioneer plant at mudflat-marsh interface
Baltic rush	*Juncus balticus*	Juncaceae	H	Also on Atlantic coast
Bulrush	*Scirpus validus*	Cyperaceae	L	Found on muddy shores
Creeping bentgrass	*Agrostis alba*	Graminae	H	Forms meadow-like swards
Dodder	*Cuscuta salina*	Cuscutaceae	L	Parasitic on many plants of the lower marsh
Eelgrass	*Zostera marina*	Zosteraceae	L	A seagrass often seen as wrack which has been washed up into the marsh
Gum plant	*Grindelia integrifolia*	Compositae	H	A composite distributed from Alaska to northern California, formerly *G. stricta*
Jaumea	*Jaumea carnosa*	Compositae	L	A succulent composite found in the low marsh
Limegrass	*Elymus mollis*	Graminae	H	Found in upper fringes of marsh and on sand dunes

(continued)

Table 6. Continued.

Common name	Scientific name	Family	Position in the marsh	Notes
Marsh clover	*Trifolium wormskjoldii*	Leguminosae	H	A legume of the high marsh and dunes
Meadow barley	*Hordeum brachyantherum*	Graminae	H	Common in mature high marshes
Milkwort	*Glaux maritima*	Primulaceae	L	Widespread in many marshes of Arctic and temperate North America
Orache	*Atriplex patula*	Chenopodiaceae	H	Also on Atlantic Coast
Orthocarpus	*Orthocarpus castillejoides*	Scrophulariaceae	L	Paintbrush owl-clover, usually doesn't form monospecific stands
Pacific silverweed	*Potentilla pacifica*	Rosaceae	H	Found in high marsh and moist sand dunes
Saltgrass	*Distichlis spicata*	Graminae	L	In marshes and on beaches, also on Atlantic Coast
Salt rush	*Juncus lesueurii*	Juncaceae	H	Found in high marsh and sand dunes
Pickleweed	*Salicornia virginica*	Chenopodiaceae	L	A succulent found in marshes and on beaches, also on Atlantic Coast
Sandspurry	*Spergularia canadensis*	Caryophyllaceae	L	Common from Alaska to northern California
Sandspurry	*Spergularia macrotheca*	Caryophyllaceae	L & H	Common from British Columbia to Baja California

(continued)

Table 6. Concluded.

Common name	Scientific name	Family	Position in the marsh	Notes
Sandspurry	*Spergularia marina*	Caryophyllaceae	L	Less common than the two previous species
Seaside plantain	*Plantago maritima*	Plantaginaceae	L	Produces a large fleshy root which is the perenniating organ
Lyngbye's sedge	*Carex lyngbyei*	Cyperaceae	L	Occupies position similar to smooth cordgrass of Atlantic and Gulf Coasts
Slough sedge	*Carex obnupta*	Cyperaceae	-	Found in nearly freshwater fringes of saline marshes
Spike-rush	*Eleocharis parvula*	Cyperaceae	L	Widely distributed along the entire Atlantic coast as well
Spike-rush	*Eleocharis palustris*	Cyperaceae	L	Widespread in temperate and cold-temperate regions of the northern hemisphere
Three-square	*Scirpus americanus*	Cyperaceae	L	Widely distributed in U.S. and southern Canada
Tufted hairgrass	*Deschampsia cespitosa*	Graminae	H	World-wide distribution
Western dock	*Rumex occidentalis*	Polygonaceae	H	Also occurs in Rocky Mountains

Figure 8. Pickleweed as a pioneer on the tidal flat in a low sandy marsh. The lighter colored halo around the vegetation is sand trapped by the plant stems. Substrate levels within the vegetation are often 2-3 inches above the surrounding substrate.

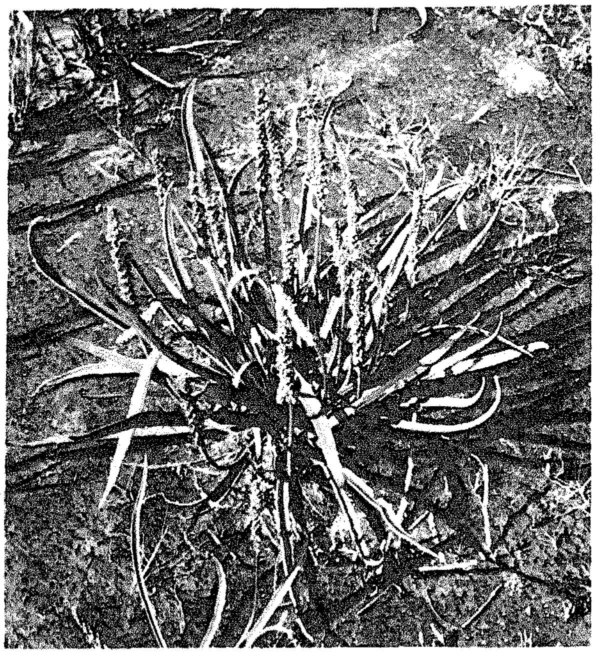

Figure 9. Seaside plantain growing in a low sandy marsh. These perennials produce large fleshy tap roots which store reserves during the winter season.

large monospecific stands, occupies a relatively low position in the intertidal zone, produces large amounts of detritus, and is more productive along the streambanks than in the back marsh.

Bulrush and Lyngbye's sedge are characteristic plants of the bulrush-sedge marsh type. Bulrush becomes predominant upstream where the water is fresher. At the mouth of the South Fork of the Siuslaw River there are 120 hectares (296 acres) of this type (Jefferson 1975). Extensive areas of this marsh type also border the Columbia River Estuary.

Tufted hairgrass and saltgrass are most common to the immature high marsh. Arrow-grass, Baltic rush, seaside plantain, pickleweed, and Lyngbye's sedge are less prevalent. Three-square, milkwort, alkaligrass (in the northern part of the region), sandspurry, and Orthocarpus may also be present. The community growing highest in this marsh type, to the point where dune grasses begin, includes tufted hairgrass, Pacific silverweed (Figure 12), marsh clover, and Baltic rush (Jefferson 1975).

Intertidal gravel marshes are less floristically diverse and are often dominated by spike-rushes of several species. Tufted hairgrass, Baltic rush, and creeping bentgrass characterize the mature high marshes. Pacific silverweed (Figure 12), gum plant, and orache are also common. Many of Oregon's mature high marshes have been diked and thus fall in the category diked salt marsh. Willapa Bay, Washington, includes some marshes of this type that have not been diked.

A typical zonation sequence for a high-salinity marsh, where the tidal water salinity is above 25 ppt, is shown in Figure 13. Sequences will vary depending on substrate, salinity, and chance. Local

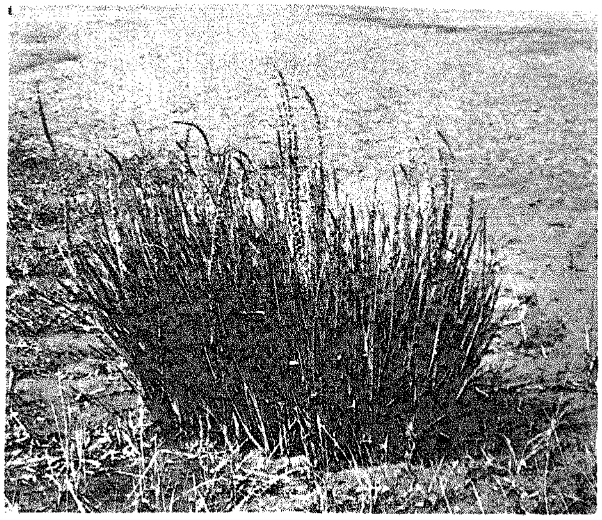

Figure 10. Circular clumps of arrow-grass in a low silty marsh. These tall plants trap litter of eelgrass detached from beds on intertidal flats.

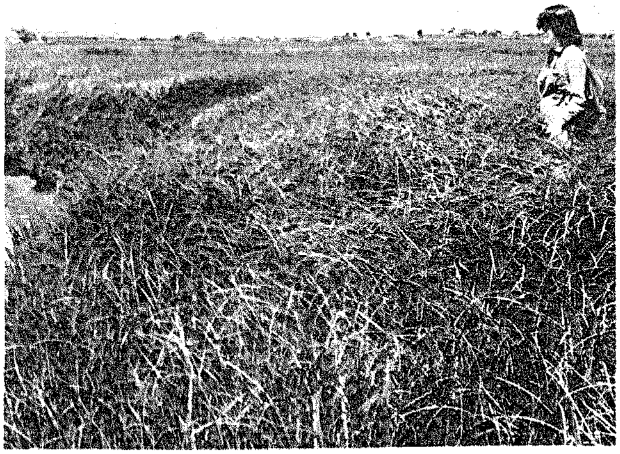

Figure 11. Lyngbye's sedge marsh in a brackish estuary. Streamside plants may be nearly twice as productive as those in the back marsh away from the creeks.

intrusion of fresh groundwater may, of course, dramatically alter this pattern. For example, a freshwater table may develop under the vegetation in the dune complex of a bay-mouth bar estuary. This water table may surface at some point in the marsh which formed on the bay side of the bar. The result is a zone of low interstitial soil salinity in an unusual setting. Plants in this zone may be particularly vigorous as a consequence of the reduced salinity stress, or the species present may be shifted as a consequence of the changed environment. The authors measured a situation where the interstitial soil salinity was 28 ppt seaward of the zone, 8 ppt in the zone of freshwater intrusion, and 18 ppt in the soil toward the upland.

A typical profile in a brackish area is depicted in Figure 14. A number of salinity regimes could produce the setting for such a sequence. Intrusion of upland freshwater could produce the proper interstitial soil salinities, or similar conditions could arise from exposure to tidal water of brackish salinity. The low elevation is occupied by Lyngbye's sedge and the upper levels by a mature high marsh association. There appear to be two forms of Lyngbye's sedge: one found along the creekbanks and the other further back from the drainage channels. On the creekbank the plants start growth earlier in the spring, are taller, and have a higher net primary productivity than the back marsh plants. This appears to be associated at least in part with the storage and remobilization of carbohydrates in the rhizomes (Gallagher and Kibby 1981). Whether the forms of sedges are ecophenes resulting from the action of environment on genetically similar plants or ecotypes whose growth and behavior are the result of genetic differences has not been investigated.

Most of the evidence regarding a similar situation for smooth cordgrass (Spartina alterniflora) indicates that the differences are environmentally controlled and that the plants are similar genetically (Smart 1982). There is, however, some evidence for certain genetic differences between smooth cordgrass plants grown in a common garden. Preliminary measurements by Gallagher, Grant, and Somers indicate that the morphological and productivity differences for the two growth forms are maintained for at least 5 years.

In some cases the vegetation zones in

Figure 12. Pacific silverweed from a mature high marsh. These plants are structurally weak and decompose rapidly in the fall after they die.

the Pacific Northwest marshes are clear and may comprise nearly monospecific stands (top of Figure 15). In other marshes the zones are diffuse and contain a mosaic of many species (bottom of Figure 15). Although these zonation patterns within the marsh are primarily of ecological interest, the boundary between the marsh and the upland is also of legal importance. This topic will be further discussed in Chapter 5.

3.2 MICROBES

Algal communities associated with Pacific Northwest tidal marshes consist of filamentous algae as well as diatoms and are abundant at times during the year. In the more silty substrates diatoms appear to be the most common forms on the creekbanks, and they also cover the collapsed dead plant material. Macroscopic forms are most conspicuous in the shallow creeks and in the tidal pools or pans. Thom (1981) reported a macroscopic brown alga, Fucus distichlis spp. edentatus, and a green form, Enteromopha intestenalis, from a site in the Grays Harbor Estuary, Washington. His sampling program was aimed at the entire estuary and in most cases the exact habitat sampled (rock, mud, creek, epiphyte, log, marsh, soil) along a transect was not reported. Published information on tidal marsh algal distribution and diversity is lacking. Our casual observations indicate that there will prove to be a rich flora (particularly the diatoms) and that many will show a general association with particular marsh types. Populations of photosynthetic bacteria are obvious in some of the tidal pools, but we have not been able to find any records of their study in the region. We were unable to find studies of the populations of decomposer microbes or aerobic or anaerobic soil bacteria.

In Atlantic coastal marshes, ATP has often been used as a measure of microbial biomass (Christian et al. 1981), and its concentration in marsh soil and tidal creek water has been used to estimate the distribution of microorganisms with respect to depth and time. Christian (1976 as cited in Christian et al. 1981) found ATP concentrations to decrease with depth in all marsh soils tested. ATP concentrations were greatest in both the soil and water during the warmest months of the year. Christian et al. (1981) concluded that 79% of the standing stock of the microbial community in the marsh is associated with the soil.

Microbes are found in the water as well as in the soil or on plant material. In the water most microbial plankton are free floating. Some of the organisms, primarily bacteria, are attached to detritus particles; it is these that are most active in consuming DOC (dissolved organic carbon) produced by smooth cordgrass and phytoplankton. Heterotrophic activity varies with the tide because the resuspension of detritus is greatest on an ebbing tide and lowest at slack tide (Christian et al. 1981). The microbial populations in salt marsh soils were not found to be nutrient limited but were inhibited by increased salinity and decreased soil moisture at the times when the marsh was not flooded (Christian et al. 1981).

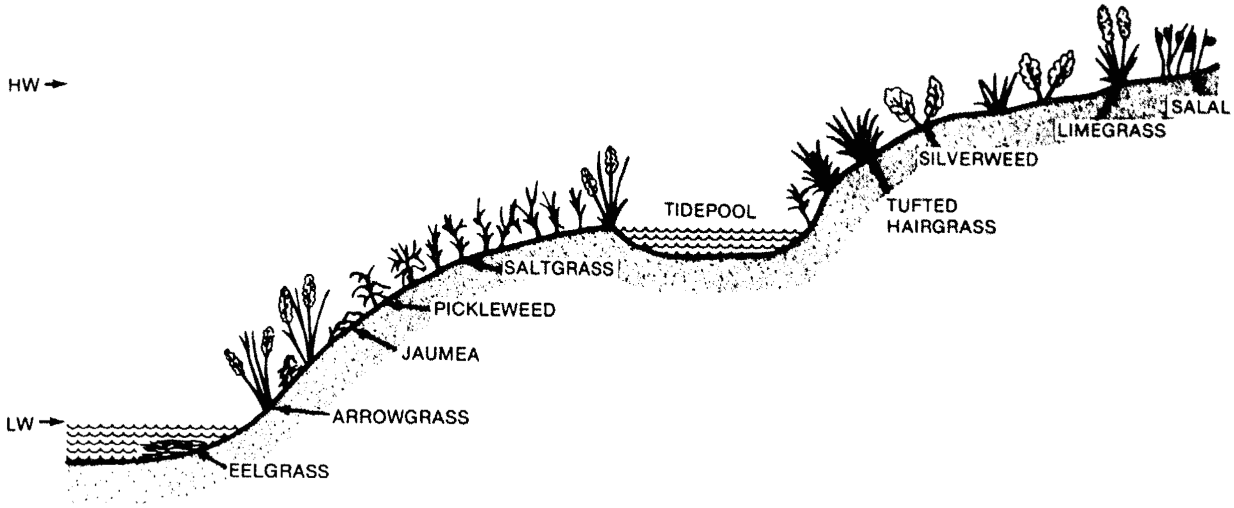

Figure 13. Typical zonation of marsh plants in a saline Pacific Northwest tidal marsh. The tidepools or pans may contain a diversity of algae. The lateral extent of the zones depends on the slope and may range from a few yards to hundreds of yards.

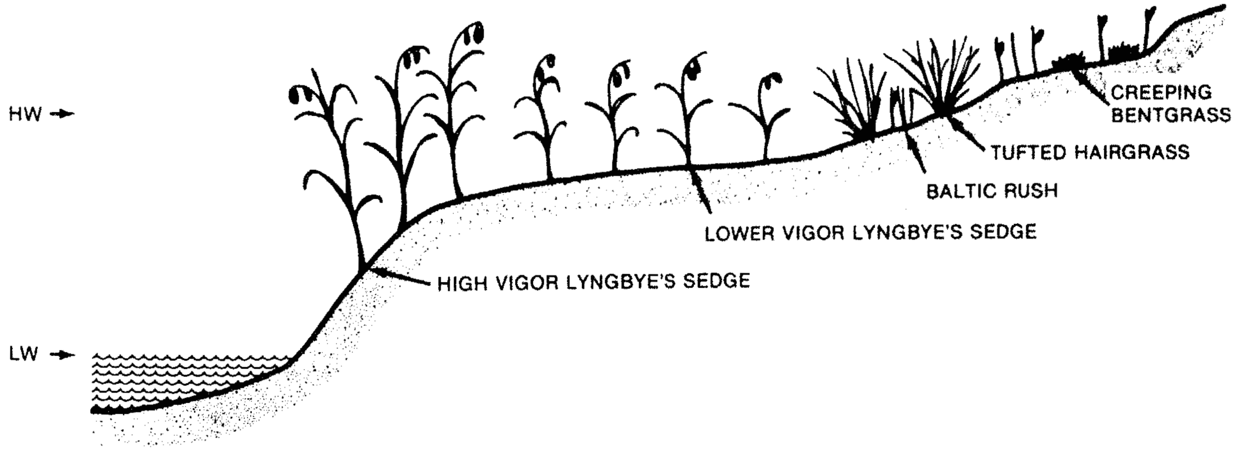

Figure 14. Possible zonation pattern in a brackish Pacific Northwest tidal marsh.

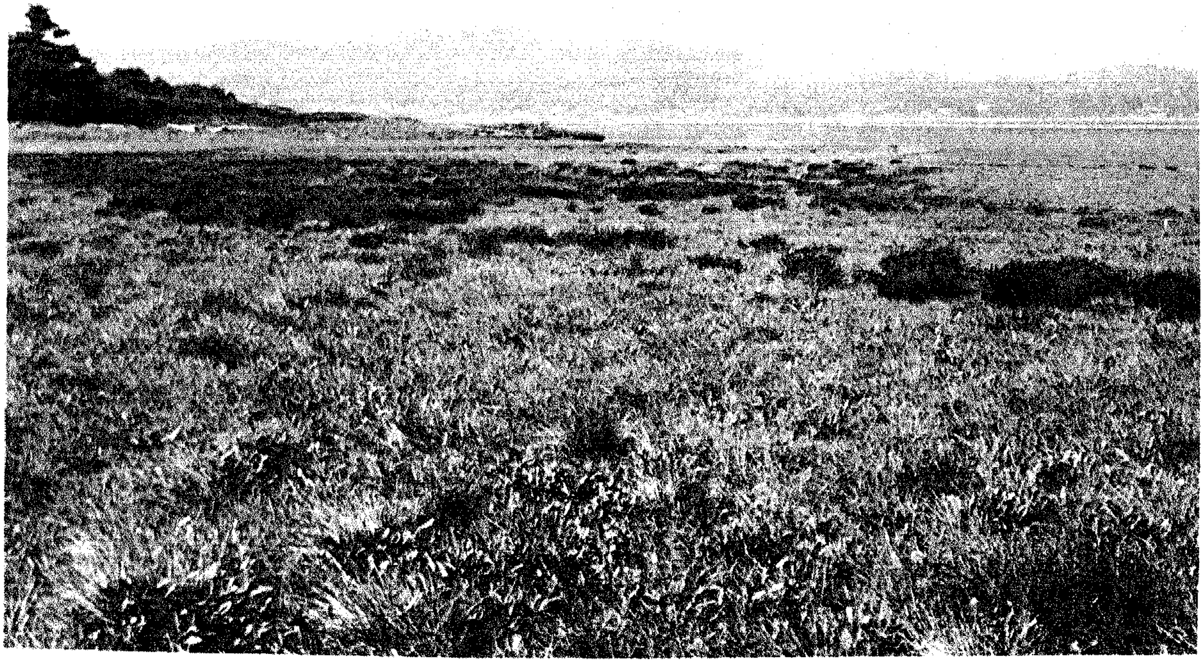

Figure 15. Examples of the range of variations in vegetational zonation in Pacific Northwest tidal marshes. The upper photograph shows distinct, nearly monospecific stands of three-square, tufted hairgrass, and slough sedge, going from lower left to upper right. The lower photograph shows diffuse zones of high plant diversity in a low sandy marsh. The dark tall clumps of plants are arrow-grass and the shorter zones are mixed areas of pickleweed, gum weed, seaside plantain, saltgrass, and Orthocarpus.

Up to this point the discussion of microorganisms has dealt with an aerobic environment; the soils of the salt marsh, however, are predominantly anaerobic. Fermentation, sulfate reduction, dissimilatory nitrogenous oxide reduction, and methanogenesis are the major processes occurring in anaerobic tidal marsh soils (Wiebe et al. 1981). Fermentation is carried out by facultative or obligate anaerobes. Facultative anaerobes can function either in the presence or absence of oxygen, but obligate anaerobes can grow only in an anaerobic environment. In the breakdown of organic matter during fermentation, an organic compound, rather than oxygen, acts as the terminal electron acceptor. Alcohols and acids are included among the possible end products of this process. These end products may then serve as substrates for other anaerobes nearby (Wiebe et al. 1981).

Sulfate acts as the terminal electron acceptor during sulfate reduction in anaerobic soils. The bacteria that carry out this reaction release sulfides into the soil. One can often smell the sulfides in marsh soils containing a large quantity of organic matter. Sulfate reducers belong to only three genera: Desulfovibrio, Desulfuromonas, and Desulfomaculum (Wiebe et al. 1981). Ewing (1983), working in the Skagit Estuary marsh in Puget Sound, found reducing conditions in the soils at most stations. Areas near pan and creek bottoms had the lowest redox potentials. In New England, marshes resemble those in the Pacific Northwest in temperature regime and often in peat development. Sulfate reduction in the northern Atlantic marshes is greater than in those further south. Howarth and Giblin (1983) found rates in Georgia to be significantly lower than those in Massachusetts. Sulfate reduction appears to be the major form of respiration in the soils in both states. We know of no similar evaluations made in the Pacific Northwest.

Nitrate is the terminal electron acceptor in denitrification and N_2 or N_2O is the end product; the result is a loss of fixed nitrogen from the soil. Anaerobic conditions are also required for this process. Dissimilatory reduction of nitrogenous oxides to ammonia may be an important process in soils where denitrification takes place (Wiebe et al. 1981).

Methane is another product produced in anaerobic marsh soils. In the process of methanogenesis, carbon dioxide or a methyl group serves as the electron acceptor. Competition between populations of methanogenic and sulfate reducing bacteria for substrates regulates methanogenesis. Nitrogenous oxides also play a regulatory role, thereby inhibiting methanogenesis. By limiting the substrates used by sulfate reducers, denitrification has been shown to increase methanogenesis (Wiebe et al. 1981). Another important factor discussed by Wiebe et al. (1981) is water flow -- the termination of water flow reduces sulfate concentration and increases methane production. Thus the four anaerobic processes and the associated bacterial populations occurring in salt marsh soils are coupled to one another.

3.3 FAUNAL COMPONENTS

Among the numerous faunal surveys of various types which have been carried out for the Pacific Northwest tidal marshes are those by Higley and Holton 1981, Hoffnagle et al. 1976, Stout 1976, and Roye 1979. We have divided the fauna into the following groups for discussion: invertebrates, fishes, birds, and mammals. Much research is still needed with these groups, especially in quantifying population sizes and cycles.

3.3.1 Invertebrates

Information on the invertebrate fauna of the Pacific Northwest marshes is fragmentary. The most comprehensive studies are those of Hoffnagle et al. (1976), who studied the Coos Bay marshes, and Higley and Holton (1981), who investigated the marshes of Siletz and Netarts Bays, Oregon. The latter authors determined the trophic structure of invertebrate marsh communities by sampling soil infauna of low and high marshes; invertebrate fauna of low (up to 15 cm above ground level) and high vegetation (sampled by terrestrial sweep nets) of the low and high marshes; fauna of the marsh debris line (Figure 16); fauna of the submerged marsh; and fauna of marsh pans, tidal creeks, and tidal flats. They found that oligochaetes and dipteran larvae dominate the fauna of the marsh soils. This contrasts with marsh soils of the Atlantic coast where polychaetes were much more abundant than oligochaetes (Cammen 1976, as cited in Higley and Holton 1981). The dominant amphipod in the Pacific Northwest was Corophium salmonis, common where low-silt marsh merged with tidal flat habitat.

Figure 16. Drift line in an Oregon low sandy marsh. Wrack consists primarily of eelgrass. These deposits are greatest after storms late in the growing season when eelgrass in the adjacent beds is senescing and burdened with epiphytes.

Mites and ticks (Order Acarina) were abundant in the vegetation closest to the ground (0 to 15 cm) in all marsh types. Collembolan, Homopteran, and Coleopteran insects also inhabitated these areas. Higher in the canopy (above 15 cm above ground level) of all marsh types Acarina, Araneae, Homoptera, Diptera, and Hymenoptera were common. Acarina, Araneae, Collembola, and Amphipoda inhabited the debris line. Overall, taxonomic diversity was greatest in the high marsh, decreasing to the low marsh and then to the debris line. Table 7 lists the invertebrate inhabitants and the stage of the life cycle found in Oregon tidal marshes. Table 8 gives approximate densities for these animals for several habitats.

Acarina and oligochaetes were moderately abundant in marsh vegetation submerged at high tide. Coleoptera, Homoptera, Hemiptera, and Collembola were also among terrestrial taxa collected from the submerged vegetation. Aquatic crustaceans, occupying marsh pans and tidal creeks, included amphipods (Corophium spp., Anisogammarus confervicolus, Orchestia traskiana), the isopod, Gnorimosphaeroma lutea, and two Cumaceans (Hemileucon spp. and Cumella spp.). Some amphipods move inland before advancing tides and find shelter in dead eelgrass.

Infaunal composition of tidal creeks and tidal pans of the marsh were similar (Higley and Holton 1981). Polychaeta, Amphipoda, Tanaidacea, and Isopoda were found, many of whose species are common to the Atlantic Coast as well. A major difference in fauna between the Atlantic and the Pacific Northwest coastal marshes is the obvious scarcity of decapods in the Northwest. Atlantic marshes are teeming with fiddler crabs (Uca) on the order of 80 to 200/m^2 (Montague et al. 1981), along with others such as the blue crab (Callinectes sapidus). Higley and Holton (1981) found only one decapod, Hemigrapsus oregonensis, which was inhabiting tidal creeks in the sedge and mature high marshes.

Mollusks common to northwest tidal marsh creeks include Alderia modesta, Macoma balthica (Higley and Holton 1981),

Table 7. Invertebrates characteristic of five Oregon marsh habitats (modified from Higley and Holton 1981). A = adult, L = larvae, N = nymphs, (-) = not divided into families but members of the order are present.

	High marsh		Low marsh		Debris line		Pan		Tidal creek	
Order	Stage	No. of families	Stage	No. of families	Stage	No. of families	Stage	No. of families	Stage	No. of families
Cnideria			A	1					A	-
Turbellaria	A	-								
Nemertea									A	-
Nematoda	A	-	A	-					A	-
Polychaeta			A	2			A	2	A	6
Oligochaeta	A	-	A	-			A	-	A	-
Gastropoda									A	1
Bivalvia									A	1
Araneae	A	-	A	-	A	-			A	-
Acarina	A	-	A	-	A	-			A	-
Ostracoda									A	-
Copepoda							A	2	A	3
Cirripedia			A	1					A	1
Cumacea			A	1			A	1	A	-
Tanaidacea									A	-
Isopoda	A	-	A	1			A	1	A	-

(continued)

Table 7. Concluded.

Order	High marsh		Low marsh		Debris line		Pan		Tidal creek	
	Stage	No. of families	Stage	No. of families	Stage	No. of families	Stage	No. of families	Stage	No. of families
Amphipoda	A	1	A	-	A	1	A	-	A	-
Decapoda									A	1
Collembola	A	5			A	3				
Diplura (Entognatha)			A	-						
Orthoptera	A	-								
Thysanoptera	A	-	A	-	A	-				
Odonata							N	-		
Hemiptera	A	2	A,N	4,1	A,N	1,1	A	1	A,N	2,1
Homoptera	A	4	A	4					A	1
Coleoptera	A	9	A	4	A	3	A	2	A	1
Trichoptera			L	1			L	1		
Lepidoptera	A	-	L	1	A	-				
Diptera	A,L	15,5	A,L	11,6	A	4	L	7	A,L	7,6
Hymenoptera	A	-	A	-	A	1				
Chilopoda	A	-								

Table 8. Approximate densities and percentages of invertebrate taxa from five habitats of an Oregon marsh (modified from Higley and Holton 1981.) (*) = taxa making up <10% of collection; (-) = no data available.

	Number of animals/m^2 (%)				
Invertebrate	Low sand	Low silt	Sedge	Immature high	Mature high
MARSH SOIL (Feb.)					
Oligochaeta	*	5,680(22)	2,990(30)	4,570(61)	990(20)
Amphipoda	*	11,610(45)	*	*	*
Diptera (larvae)	23,880(76)	7,740(30)	4,480(45)	1,870(25)	2,570(52)
Areneae	*	*	*	*	490(10)
Acarina	3,770(12)	*	*	*	*
LOWER CANOPY VEGETATION (Sept.) (ground level to 15 cm)					
Acarina	450(84)	1,080(69)	3,770(95)	1,710(62)	2,670(54)
Isopoda	*	240(15)	*	*	*
Collembola	*	*	*	830(30)	1,730(35)
Homoptera	*	250(15)	*	*	*
UPPER CANOPY VEGETATION (Sept.) (above 15 cm above ground level)					
Araneae	*	*	*	17(15)	*
Acarina	30(33)	680(47)	510(52)	14(12)	*
Homoptera	10(10)	570(40)	320(33)	25(21)	110(53)
Diptera	40(45)	*	*	40(35)	*
Hymenoptera	*	*	*	18(16)	40(18)
DEBRIS LINE (Aug.)					
Acarina	10,210(63)	-	-	-	-
Collembola	3,240(20)	-	-	-	-
SUBMERGED VEGETATION (Feb.) (at high tide)					
Oligochaeta	*	*	690(22)	380(49)	-
Acarina	8,030(96)	*	1,410(45)	*	-
Isopoda	*	6,480(76)	*	*	-
Diptera	*	*	940(30)	160(21)	-

(continued)

Table 8. Concluded.

Invertebrate	Number of animals/m^2 (%)				
	Low sand	Low silt	Sedge	Immature high	Mature high
PAN WATER (April)					
Oligochaeta	-	-	-	120(11)	1,370(46)
Copepoda	-	-	-	580(54)	*
Amphipoda	-	-	-	350(32)	*
Diptera (larvae)	-	-	-	*	1,190(40)
TIDAL CREEK SOIL (Nov.)					
Polychaeta	-	-	20,220(10)	-	7,660(20)
Oligochaeta	-	-	145,590(72)	-	18,380(48)
Amphipoda	-	-	*	-	5,740(15)
TIDAL CREEK WATER (Nov.)					
Cnidaria	-	-	*	50(10)	-
Nemertea	-	-	*	130(28)	-
Polychaeta	-	-	1,070(22)	*	-
Oligochaeta	-	-	1,220(25)	100(20)	-
Cumucea	-	-	490(10)	*	-
Amphipoda	-	-	970(20)	120(26)	-

Macoma inconspicua, and the soft-shelled clam _Mya arenaria_ (Macdonald 1977). _Macoma nasuta_ and _Cryptomya californica_ were also found in tidal creeks of Grays Harbor, Washington (Macdonald 1977). The major conclusion in the species inventory carried out by Hoffnagle et al. (1976) was that in a particular marsh one or two species of invertebrates dominated while the rest were few in number and random in distribution.

It is not known if or how the tidal marshes are important to the economically important invertebrates of the estuary such as the Dungeness crab and Japanese oyster. Large numbers of small Dungeness crabs have been found in the upper reaches of the Coos Bay Estuary (Roye 1979). More study, however, is necessary to ascertain whether the tidal marsh plays a valuable role in the survival of these animals.

3.3.2 Fishes

The role of tidal marshes as nursery and feeding grounds for salmon and other fish has yet to be proven in Pacific Northwest marshes. However, evidence to support their role in the fishes' life cycle is beginning to accumulate. Inventories of fish have been made in various estuaries of the Pacific Northwest, but much less information is available on the fish that inhabit the tidal marshes (Table 9). Hoffnagle et al. (1976) surveyed fish species of tidal creeks of the marshes of Coos Bay, Oregon, and also carried out gut analysis to obtain information on feeding habits. The two dominant fishes of these marshes were the shiner perch and the staghorn sculpin. Major food sources included amphipods, especially _Corophium_, in the case of the staghorn sculpin and harpacticoid copepods for the shiner

Table 9. Common and scientific names, marsh habitat, and life stage of some fishes associated with marshes of the Pacific Northwest (Hoffnagle et al. 1976; Levy et al. 1979; Northcote et al. 1979; Higley and Holton 1981).

Common name	Scientific name	Marsh habitat	Life stage
Anadromous species			
Chinook salmon	*Oncorhynchus tshawytscha*	Sedge marsh - edge	Juvenile
Chum salmon	*Oncorhynchus keta*	Low marsh - level portion	Juvenile
Coho salmon	*Oncorhynchus kisutch*	Marsh creek	Juvenile
Longfin smelt	*Spirinchus thaleichthys*	Marsh creek	
Pink salmon	*Oncorhynchus gorbuscha*	Marsh creek	Juvenile
Sockeye salmon	*Oncorhynchus nerka*	Marsh creek	Juvenile
Marine species			
Northern anchovy	*Engraulis mordax*	Sedge marsh - edge	
Shiner perch	*Cymatogaster aggregata*	Sedge marsh - edge and creek	Juvenile
Staghorn sculpin	*Leptocottus armatus*	High marsh - edge, creek and pan Low marsh - edge and creek	Juvenile to young adult
Starry flounder	*Platichthys stellatus*	Low marsh - level portion, edge and creek	
Surf smelt	*Hypomesus pretiosus*	Low marsh - level portion	Juvenile
Freshwater species			
Peamouth chub	*Mylocheilus caurinus*	Marsh creek	
Prickly sculpin	*Cottus asper*	Marsh creek	
Threespine stickleback	*Gasterosteus aculeatus*	High and low marsh - edge, creek and pan	Juvenile to adult

perch. Detritus particles from salt marsh plants are the major food of Corophium; thus there is a link between fish and marsh plants. In Hoffnagle's study, juvenile fish dominated the sites, which also supports the nursery role of the tidal marshes.

Higley and Holton (1981) found that the species diversity of fish in the Pacific Northwest marsh habitats was not as great as in those along the Atlantic coast. They suggested that perhaps this is due to lower salinity (and therefore fewer marine species are temporary residents) or to the lesser extent of Northwest marshes. In both high and low marshes at Netarts and Siletz Bays, staghorn sculpin and threespine stickleback dominated. Other species captured by seine and trawls included juvenile surf smelt and juvenile chum salmon. In addition to the shiner perch and the threespine stickleback in a slough adjoining a sedge marsh, nine other species were captured but in lower numbers. Among these less common species were northern anchovy, starry flounder, juvenile chinook salmon, and the shiner perch (Higley and Holton 1981).

Most information on fish residents of Oregon and Washington estuaries comes from angler catch data. Comprehensive surveys have not been done in most cases; studies investigating the utilization of the marshes by these fish are especially lacking. For this information we have to rely on the studies done in British Columbia and assume that many of their conclusions are transferrable to other Pacific Northwest estuarine systems, at least until such studies are completed in Oregon and Washington. Chinook and coho salmon (chum salmon are found in a few of the estuaries), steelhead trout, cutthroat trout, shad, and sturgeon frequent many of Oregon's estuaries (Kreag 1979a, b; Roye 1979). Other common fish include various species of perch, starry flounder, Pacific staghorn sculpin, Pacific herring, surf smelt, and northern anchovy. Many other species have been reported in these estuaries; at least 66 species are known to Coos Bay.

3.3.3 Birds

Salt marshes of Pacific Northwest estuaries are located along the Pacific Flyway for migratory waterfowl. Along with the tidal flats and open water, the marshes provide prime habitats for feeding and wintering. Magwire (1976a) conducted the most comprehensive survey on marsh utilization by birds of the Pacific Northwest in a summer study at Coos Bay, Oregon. He studied six marshes at Coos Bay by dividing them into the following zones: shrubs and trees at the upper marsh edge, high marsh, middle marsh, low marsh, mudflat, and water. Bird observations were made as he traversed each marsh from upland to mudflat. He found that 28 bird species utilized the marsh proper, including the air space over the marsh. These are listed in Table 10 according to the location in the marsh where they were observed.

The five swallow species (barn, cliff, rough-winged, violet-green, and tree) are migratory birds and are commonly seen over the marsh from April to August. They have large mouths and prey on flying insects. None of the swallows build their nests in the marsh, but the barn swallow uses mud taken from the marsh edge to build its nest, usually under building eaves (Magwire 1976a).

The widely distributed song sparrow, the most common bird Magwire observed over the marsh, often nests in marsh plants, in snags found in the marsh, or in the brush adjacent to the upland. These birds can be seen probing for worms and insects in the marsh and its creeks (Magwire 1976a).

The finches were observed to eat seeds of arrow-grass but were seen only infrequently in the marsh (Magwire 1976a).

The northern harrier builds its nest on the marsh surface and soars over the marsh searching for small mammals. The red-tailed hawk generally lives and hunts outside the marsh but was occasionally seen in the upper part of the marsh (Magwire 1976a).

Table 10. Bird observations in salt marshes at Coos Bay (modified from Magwire 1976a).

Species	Upland	Marsh			Mudflat	Water
		High	Middle	Low		
Mallard (*Anas platyrhynchos*)					x	x
Turkey vulture (*Cathartes aura*)	x	x	x	x	x	x
Northern harrier (*Circus cyaneus*)				x		
Red-tailed hawk (*Buteo jamaicensis*)	x	x	x			
Great egret (*Casmerodius albus*)					x	
Great blue heron (*Ardea herodias*)	x	x	x	x	x	x
Green-backed heron (*Butorides striatus*)	x	x	x	x	x	
Virginia rail (*Rallus limicola*)		x	x	x	x	x
Killdeer (*Charadrius vociferus*)					x	
Sandpipers[a]				x	x	
Band-tailed pigeon (*Columba fasciata*)	x	x				
Common nighthawk (*Chordeiles minor*)		x	x	x	x	x
Belted kingfisher (*Ceryle alcyon*)				x		x
Barn swallow (*Hirundo rustica*)	x	x	x	x	x	x
Cliff swallow (*Hirundo pyrrhonota*)	x	x	x	x	x	x
Northern rough-winged swallow (*Stelgidopteryx serripennis*)		x	x	x	x	x
Violet-green swallow (*Tachycineta thalassina*)		x	x	x	x	x
Tree swallow (*Tachycineta bicolor*)	x	x	x	x	x	x
American crow (*Corvus brachyrhynchos*)			x	x	x	
Marsh wren (*Cistothorus palustris*)		x	x	x		
American robin (*Turdus migratorius*)	x	x	x	x		
European starling (*Sturnus vulgaris*)	x	x	x	x	x	
Common yellowthroat (*Geothlypis trichas*)			x			
Red-winged blackbird (*Agelaius phoeniceus*)			x			
Purple finch (*Carpodacus purpureus*)			x			
American goldfinch (*Carduelis tristis*)	x	x	x			
Song sparrow (*Melospiza melodia*)	x	x	x	x	x	

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[a] Sandpipers include the western sandpiper (*Calidris mauri*), least sandpiper (*Calidris minutilla*), white-rumped sandpiper (*Calidris fuscicollis*), and Baird's sandpiper (*Calidris bairdii*).

Common to the higher marshes is the long-billed marsh wren, nesting a foot or two above the ground in the tall vegetation of this zone. This bird feeds on marsh insects, snails, and spiders in the grass and on the ground (Magwire 1976a).

Virginia rails build their well-concealed nests close to the ground in the marsh. Their long curved bills are especially suited to probing in the mud for worms, snails, larvae, etc. They also feed on plant seeds. Soras rails were also occasionally sighted in the marsh areas of Coos Bay (Magwire 1976a).

The great blue heron is seen in those marshes adjacent to large mudflats. Herons feed on fish and invertebrates in shallow water at the edge of the marsh and in marsh creeks. They seek refuge in the marsh to restore and preen their feathers but do not nest there. Their nests are built in large rookeries in Sitka spruce or hemlock (Magwire 1976a).

Based on a census made each December, Roye (1979) associated the following birds with Coos Bay salt marshes: American wigeon, black-bellied plover, willet, common goldeneye, northern harrier, bald eagle, red-tailed hawk, great blue heron, green heron, American coot, tundra (or whistling) swan, Canada goose, gadwall, snowy egret, Virginia rail, long-billed curlew, pectoral sandpiper, knot, American bittern, Great egret, sora common snipe, and mallard (see Table 10). The relative abundance of these birds in the marshes has been determined by Roye (1979) and is given in Table 11. Many of these species utilize other estuarine habitats as well.

3.3.4 Mammals

The most comprehensive study on mammal populations of tidal marshes in Oregon was done by Magwire (1976b) in the salt marshes of Coos Bay. Mammals are primary consumers, predators, and scavengers in the salt marsh food web. The larger mammals generally range widely and are therefore not restricted to marsh habitats. Magwire (1976b) found the raccoon to be the most frequent marsh visitor of the larger mammals. This omnivore feeds on fruits, fish, invertebrates, and small vertebrates and mammals, as well as eggs. Another marsh visitor is the black-tailed deer, which browses in brush areas generally outside the marsh. Matted marsh grass and the many tracks indicate that the deer utilize the marsh as a refuge. Deer have been observed by the authors feeding on arrow-grass in the marshes. Beaver live at the edge of one of the marshes of Coos Bay, where the freshwater meets the estuary. They feed on bark of deciduous trees at the marsh's edge. Other large mammals reported to frequent marsh areas of Coos Bay are muskrat, mink, river otter, weasels, grey fox, coyote, and bobcat (Magwire 1976b). The abundance of these animals in the marsh is primarily related to the proximity of urban areas. The closer the urbanization, the fewer the animals. A list of the common and scientific names of those species frequently associated with the marshes is given in Table 12.

Magwire (1976b) captured six species of small mammals in a study of low sandy, low sedge, immature high, and high marshes at Coos Bay. The vagrant shrew made up 71% of the captures; the next most abundant species was the deer mouse, comprising 23% of the small mammal catch. Four other species were captured more rarely - the Oregon meadow mouse, western red-backed mouse, the black rat, and the Trowbridge shrew.

Magwire (1976b) correlated the relationship between captures and marsh type. The deer mouse was most abundant in the high marsh. Its numbers declined as distance into the marsh from the terrestrial side increased. The deer mouse apparently resides in the dense trees and shrubs just beyond the edge of the marsh and feeds on fruits, seeds, and insects. The vagrant shrew is an insectivore and prefers the dense herbaceous cover of the immature high marshes and sedge marshes. Here they build their nests directly on the ground in the highest part of a particular area. There was no correlation between abundance and distance into the marsh; the vagrant shrew was observed throughout the entire marsh. However, more were captured near

Table 11. Common and scientific names and relative abundance of birds associated with marshes of Coos Bay (Roye 1979).

Common name	Scientific name	Relative abundance[a]
American bittern	*Botaurus lentiginosus*	Rare
American coot	*Fulica americana*	Abundant
American wigeon	*Anas americana*	Abundant
Bald eagle	*Haliaeetus leucocephalus*	Rare
Black-bellied plover	*Pluvialus squatarola*	Common
Canada goose	*Branta canadensis*	Rare
Great egret	*Casmerodius albus*	Common
Common goldeneye	*Bucephala clangula*	Uncommon
Common snipe	*Gallinago gallinago*	Uncommon
Gadwall	*Anas strepera*	Uncommon
Great blue heron	*Ardea herodias*	Common
Green-backed heron	*Butorides striatus*	Uncommon
Red knot	*Calidris canutus*	Uncommon
Long-billed curlew	*Numenius americanus*	Rare
Mallard	*Anas platyrhynchos*	Common
Northern harrier	*Circus cyaneus*	Uncommon
Pectoral sandpiper	*Calidris melanotos*	Rare
Red-tailed hawk	*Buteo jamaicensis*	Uncommon
Snowy egret	*Egretta thula*	Rare
Sora	*Porzana carolina*	Rare
Virginia rail	*Rallus limicola*	Uncommon
Tundra swan	*Cygnus columbianus*	Rare
Willet	*Catoptrophorus semipalmatus*	Uncommon

[a] abundant = ≥50/day/observer, common = 10-49/day/observer, uncommon = 0-9/day/observer, rare = ≤5/day/observer.

Table 12. Common and scientific names of some mammal species associated with the marshes of the Pacific Northwest.

Common Name	Scientific Name	Common Name	Scientific Name
Residents		Visitors	
Black rat	*Rattus rattus*	Beaver	*Castor canadensis*
Deer mouse	*Peromyscus maniculatus*	Black tailed deer	*Odocoilous hemionus columbianus*
		Bobcat	*Lynx rufus*
Oregon meadow mouse	*Microtus oregonii*	Coyote	*Canis latrans*
		Grey fox	*Urocyon cinereoargenteus*
Shrew	*Sorex vagrans*	Mink	*Mustela vison*
		Muskrat	*Ondatra zibethicus*
Trowbridge shrew	*Sorex trowbridgii*	Raccoon	*Procyon lotor*
Western red-backed mouse	*Clethrionomys occidentalis*	River otter	*Lutra canadensis*
		Weasel	*Mustela* spp.

logs which had been washed into the marsh.

During tidal inundation the deer mouse seeks higher terrestrial ground while the vagrant shrew remains in its own locale in the tops of the emergent marsh vegetation or on top of logs or other debris. As might be expected, these marsh inhabitants are more vulnerable to predation by marsh hawks and owls during tidal inundation (Magwire 1976b).

In a survey done in the salt marshes adjacent to Netarts Bay, only one mammal, the vagrant shrew, was encountered (Stout 1976). The paucity of mammal life in that marsh was attributed to the lack of freshwater. Dew, precipitation, and food fluids provide the small mammal inhabitants of the salt marsh with freshwater (Magwire 1976b). An interesting adaptation of the deer mouse is that those captured from a salt marsh can survive indefinitely on a diet of dry food and seawater, while those taken from a mountain region cannot (Fister, as cited in Magwire 1976b).

CHAPTER 4

ECOLOGICAL INTERACTIONS

Previous chapters have examined the distribution, types, areal expanse, and development of tidal marshes, the marsh flora and fauna, and the physical and chemical environment in which the biota live. From this we know where the marshes are and what the living conditions are for the biota which were discussed in Chapter 3. We have examined James Bonner's first question of ecology, "Who lives where and why?" We also touched on his second question "who eats whom?" This chapter establishes a framework into which various short food chains fit to develop a holistic view of the tidal marsh ecosystem. Potential interactions between the marsh and adjacent ecosystems will be examined, and in a broad sense we will examine Bonner's final ecological question, "What is the biology of togetherness?"

4.1 ECOLOGICAL PROCESSES WITHIN THE MARSH

A generalized conceptual model of tidal marsh components and their interactions is presented in Figure 17. The model was assembled from data and observation from Pacific Northwest marshes and experience in Atlantic Coast marshes. Although the model is based on carbon cycling, any material (or energy) could be so discussed using the diagram.

The compartments of the model are lumped categories of functionally similar organisms. For example, X^3, the aerobic heterotrophs, is made up of birds, insects, deer, and other herbivores in the aerial component. The same compartment in the water column consists of fish, amphipods, mussels, oysters, and bacteria. Within the sediments, X^3 is comprised primarily of meiofauna and bacteria. An important difference between Pacific Northwest and East Coast marshes is the lack of macroinvertebrates, particularly snails and crabs (Uca) in the X^3 compartment. The anaerobic heterotrophs, X^{10}, are bacteria. Similarly, X^2, the living marsh plants, encompasses all types found in the Pacific Northwest marshes. The algae, X^8, includes floating (phytoplankton) and attached (micro- and macrobenthic) algae. The most diverse compartment is X^4, POC. This ranges from dead marsh plants and algae to imported litter (as eelgrass, drift logs, or mammalian feces) to fine particulate matter from any of these sources.

Table 13 lists some typical processes by which carbon is transferred between the ecological components shown in Figure 17. For example, the export of aerobic heterotrophs in the air (F 3,5) could represent the loss of insects directly or through insectivorous birds (Pfeiffer and Wiegart 1981). Quantitative data on most flux notes listed in Table 13 and the standing crops of the functional compartments in Figure 17 are not available for salt marshes of the Pacific Northwest. Our experience has shown that the marshes of the Pacific Northwest are structurally and functionally similar to eastern Spartina alterniflora marshes. Studies of production, decomposition, and grazing support this concept.

4.1.1 Primary Production

There are two major primary producer groups in the system: emergent marsh plants (or angiosperms) and algae (benthic algae, phytoplankton, and macro-algae). The emergent macrophytes appear dominant. Algal standing crop, biomass, and productivity have not been quantified. Data does exist for the nearby mudflats and seagrass beds, but we feel the marsh algal production is much more like that of

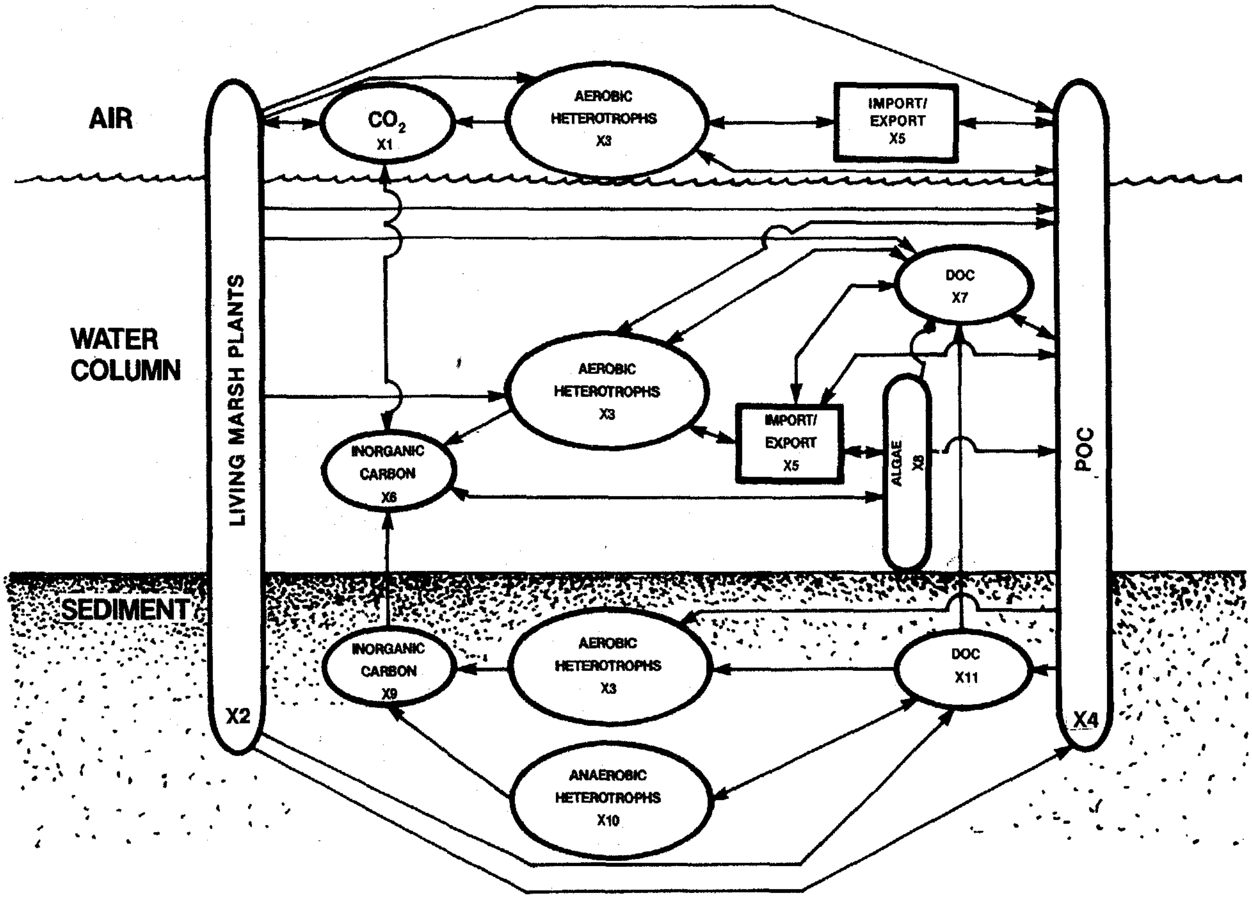


Figure 17. Conceptual model of carbon flow between components of tidal marsh ecosystems in the Pacific Northwest.

the Middle Atlantic marshes than that of the geographically closer Pacific Northwest tidal flats, seagrass beds, or southern California marshes. We would expect it to average approximately 100g C/m^2/yr.

Macrophytic seed-bearing plants in Oregon have a wide range of productivity from 100g C/m^2/yr to as much as 1000g C/m^2/yr (Gallagher and Kibby in prep.). Others working along the Pacific Northwest coast have found similar ranges in primary productivity. Burg et al. (1980), for example, working in southern Puget Sound found production ranging from 90 gram dry weight (gdw)/m^2/yr for a salt marsh sandspurry (<u>Spergularia marina</u>) association to 1390 gdw/m^2/yr for the Lyngbye's sedge association. Eilers (1975) measured net primary productivity ranging from 520 to 1940 gdw/m^2/yr. When these values are converted to a carbon base (approximately 45% of dry weight), these last two data sets are similar to those measured by Gallagher and Kibby (in prep.). Kibby et al. (1980) have depicted many of the plants in the Pacific Northwest marshes and given production estimates (Table 14). They also have devised a series of field techniques to be used in making rapid primary production estimates of wetland sites.

As is the case in many middle Atlantic salt marshes, the location of plant stands relative to marsh creeks affects their productivity. Although the aerial growth rates of streamside and back marsh Lyngbye's sedge are similar, the seasonal production is greater for the streamside plants (Gallagher and Kibby 1981). The streamside plants develop a canopy from underground reserves in the late winter

Table 13. Representative processes of carbon flow in salt marsh communities. Numerical designations refer to direction of flow between the compartments of Figure 17; for instance, F (1,2) shows carbon flow from the atmosphere (X1) to plants (X2) by the photosynthetic pathway.

Component	Fluxes	Ecological processes
Aerial	F (1,2)	Marsh plant photosynthesis
	F (2,1)	Marsh plant respiration
	F (2,3)	Grazing (primarily by insects), pathogenic infection
	F (2,4)	Plant death, fragmentation
	F (5,4)/(4,5)	POC import, export (by wind, gravity, animals)
	F (5,3)/(3,5)	Immigration, emigration (primarily mammals, birds, insects)
	F (3,4)	Fecal production and death
	F (4,3)	Detrital consumption
	F (3,1)	Microbial and animal respiration
Water column	F (2,7)	Leaching from leaves and stems
(on site in marsh and in tidal creeks)	F (2,3)	Grazing (possibly by insects in air pockets), pathogenic infection
	F (7,5)/(5,7)	Tidal DOC export and import
	F (7,4)	DOC flocculation, sorption on POC
	F (4,7)	Leaching from POC
	F (5,3)/(3,5)	Immigration or emigration of animals (fish, crustaceans), waterborne microbes
	F (7,3)	DOC uptake (primarily by microbes)
	F (3,7)	DOC release by excretion
	F (3,6)	Microbial and animal respiration
	F (3,4)	Fecal production and death

(continued)

Table 13. Concluded.

Component	Fluxes	Ecological processes
Water column (cont.)	F (4,3)	Detrital consumption and microbial activity
	F (5,4)/(4,5)	POC import and export by tidal water (often as litter)
	F (8,7)	Excretion and extracellular release
	F (8,4)	Algal death, fragmentation
	F (2,4)	Plant death, fragmentation
	F (6,1)	CO_2 release
	F (1,6)	CO_2 solution
	F (9,6)	Diffusion from sediments
	F (8,5)/(5,8)	Transport by tidal water
	F (8,6)	Algal respiration
	F (6,8)	Algal photosynthesis
Sediment	F (2,11)	Leaching from roots and rhizomes
	F (11,7)	Leaching from substrate
	F (2,4)	Root and rhizome death and fragmentation
	F (4,11)	Leaching (primarily from roots and rhizomes)
	F (11,3)	DOC uptake (primarily by microbes)
	F (11,10)	DOC uptake by anaerobic bacteria
	F (10,11)	Cellular release
	F (4,3)	Detrital consumption
	F (3,9)	Bacterial and benthic animal respiration
	F (10,9)	Anaerobic bacterial respiration and methanogenesis
	F (9,6)	Inorganic carbon exchange

and early spring, a time when light and temperature conditions ordinarily are not optimum. The rapid spring growth from underground reserves in roots and rhizomes correlates with the ultimate high annual production of these streamside sedges. When temperature and light become more favorable as the growing season progresses, the streamside plants have a larger canopy to intercept light and photosynthesize than do the back marsh plants. Although the growth rate per unit of tissue is similar, total growth is faster in the streamside plants where more leaf area is present when growth conditions become favorable.

These differences in the management of underground reserves may be coupled with environmental factors such as better waterflow through the streamside soils which results in the removal of toxic substances and the aeration of the root zone. The greater sediment deposition and reworking rates which seem to occur on some of the streambanks in the younger marshes may also be important. These actions produce a fertilization of sorts for the plants near the streams.

We found that growth increased in back marsh Lyngbye's sedge in response to nitrogen fertilization (unpublished data). Although they have not been tested, it is likely that at least some of the other Pacific Northwest species would respond similarly. Other nutrients, light, temperature, and salinity may be factors altering marsh production, but data to resolve this question are not available for the Pacific Northwest marshes.

The major source of belowground carbon in most systems is from root and rhizome growth. In southeastern Atlantic coast marshes, production ranges widely but may equal or exceed aerial net primary production (Gallagher and Plumley 1979). In local situations where silt deposition from turbid freshets buries large quantities of aboveground plant material in the sediment, aerial production can also contribute significant quantities to belowground carbon pools. We have not observed such sites in Washington or Oregon but have seen situations where a large portion of the season's primary production appears to be buried in the Fraser River delta in southwestern Canada.

Table 14. Primary production estimates of selected Oregon marsh plants (from Kibby et al. 1980).

Common name	Scientific name	Net primary production ($g/m^2/yr$)
Lyngbye's sedge	Carex lyngbyei	1,850
Pickleweed	Salicornia virginica	1,660
Saltgrass	Distichlis spicata	1,300
Pacific silverweed	Potentilla pacifica	900
Arrow-grass	Triglochin maritima	900
Three-square	Scirpus americanus	550
Baltic rush	Juncus balticus	450

4.1.2 Decomposition

Gallagher et al. (in press, a) have measured the decomposition rates of marsh grasses in Oregon. Rates were comparable to those measured by Gallagher and Pfeiffer (1977) in the southeast Atlantic coast in spite of the higher annual temperature at the lower latitude site. In addition to cool winter temperatures which regulated decomposition, another major factor was the moisture content of the dead plant tissue (POC). Those plants which had the greatest percentage of supportive tissue decomposed slower than those that collapsed to the ground soon after they died. Tissue nitrogen correlated with decomposition rate in several cases.

We have no direct evidence for the release of DOC from living marsh plants in Oregon and Washington. Gallagher et al. (1976) have demonstrated that the process occurs in smooth cordgrass marshes of the Atlantic coast; it may be presumed to also occur in plants in Pacific Northwest marshes.

Leaching of DOC from the POC compartment takes place as the detritus ages or is broken down. In Oregon marshes rates of DOC leaching from eelgrass litter decreased more rapidly with aging in the Pacific silverweed marsh than in the pickleweed zone. The consumption of POC of either plant or animal origin by aerobic heterotrophs may take the form of bacterial decomposition. Gallagher and Pfeiffer (1977) found that the release of DOC to the water column from standing dead smooth cordgrass was inversely related to microbial respiration rates. This was interpreted as an uptake of labile DOC by the bacteria. When microbial populations were high, little DOC was released into the surrounding water. Respiration was also found to vary with plant species. Microbial respiration was greater on dead smooth cordgrass than on dead black needlerush. Christian et al. (1981) suggested that an equilibrium exists between microbial populations and production of substrate. DOC in estuarine water increases when the microbial populations are controlled by predation by protozoa and detritivores; however, it never reaches levels high enough to be transported out of the particular tidal stream in which it was produced.

Christian et al. (1981) used oxygen uptake to measure microbial metabolism. Respiration rates of subtidal sediments and of soils in the area of tall smooth cordgrass were comparatively high ($Q^{10} = 1.20$) relative to soils in the short smooth cordgrass areas ($Q^{10} = 1.27$); all varied seasonally. The low Q^{10} values indicate the predominant role that physical rather than biological processes play in the transfer process.

4.1.3 Grazing

In smooth cordgrass marshes less than 10% of the plants are grazed; most biomass eventually enters the detritus foodweb (Pfeiffer and Wiegert 1981). Aerobic heterotrophs which include insects and amphipods feed on POC in the litter layer in the air, water column, and sediments.

Higley and Holton (1981) have shown that there is a diverse community of insects in Oregon marshes, but the flux of material through them has not yet been measured. Insect studies indicated that Diptera and Homoptera (with large numbers in the lower marsh) comprised most of the insects caught in sweeps in the marshes of Coos Bay. Energy flow studies indicated leafhoppers (Cicadellidae) consumed 7.3% of saltgrass production with 2% being assimilated; thus, assimilation efficiency was 27.5% (Hoffnagle et al. 1976). Similar values are reported by Smalley (1960, as cited in Hoffnagle et al. 1976) for insects of Atlantic coast smooth cordgrass marshes. Therefore both insect assemblages of northwest marshes and their energetics resemble those found in east coast marshes.

Hoffnagle et al. (1976) have studied the role of marsh grass detritus in the diets of the bay mussel (*Mytilus edulis*) and the Japanese oyster (*Crassostrea gigas*). In order to simulate the natural diet, detrital particles were prepared by grinding dried plant material in filtered seawater. The relative importance of different food sources for bay mussels (as measured by survival) is as follows: Lyngbye's sedge, saltgrass, pickleweed, a mixture of 4 plants (the above 3 plus bulrush), phytoplankton, bulrush, and eelgrass. For the Japanese oyster, pickleweed appeared to be the most important followed by saltgrass, phytoplankton, bulrush, Lyngbye's sedge, mixed marsh plants, and eelgrass.

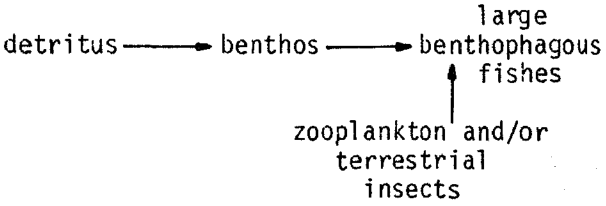
4.1.4 Food Webs

For many specific problems it is useful to decompose small parts of the general model into submodels. For example, food webs involving salmonids are of commercial importance in the Pacific Northwest and have been described by a number of workers including Northcote et al.

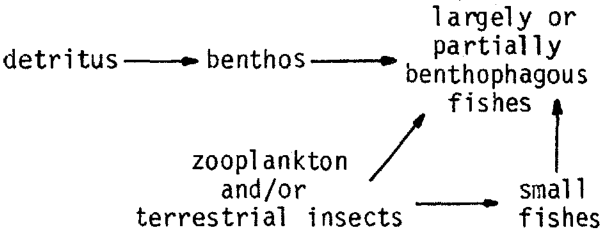
(1979) from whom the following examples were taken. At least six fish species and size classes (leopard dace, largescale sucker adults, prickly sculpin juveniles, mountain whitefish, juvenile chum salmon, and starry flounder juveniles) of the lower Fraser River estuary may be included in a food web consisting of three compartments:

detritus → benthos → benthophagous fishes

In contrast, the largescale sucker (<300 mm), chinook salmon (<50 mm), threespine stickleback, peamouth chub (<75 mm), redside shiners, and juvenile sockeye salmon are involved in a more complex food web. Terrestrial insects and northern squawfish juveniles contribute up to 43% of the diet of the latter two species. The resulting foodchain is:



Where small fishes are prey the food web becomes:



Prickly sculpin (>50 mm), white sturgeon (125 to 720 mm), starry flounder (>100 mm), staghorn sculpin (100 to 300 mm), northern squawfish (>150 mm), Dolly Varden (181 to 430 mm), and peamouth chub (75 to 150 mm) are involved in this food web.

Chinook salmon juveniles (50 to 110 mm in length) and peamouth chub adults are not strictly benthic detritivores. A large portion (32%) of the diet of juvenile chinook salmon is fish, and in the case of peamouth chub adults, 19% of their diet consists of benthic suspension feeders and 25% of fish. Of course the benthic suspension feeders and the fish (via zooplankton) are dependent on suspended detritus coming from the benthic detritus source.

The stomach contents of fish collected at Netarts and Siletz Bays were analyzed by Higley and Holton (1981). Terrestrial prey, including adult insects and spiders in small quantities and dipterous larvae and pupae, were consumed only by the chum salmon. Chum salmon also fed on flatfish larvae and cumaceans (Hemileucon spp.). Staghorn sculpin, threespine stickleback, and juvenile chum salmon consumed primarily aquatic animals, amphipods, harpacticoid copepods, cumaceans, oligochaetes, and polychaetes. Starry flounder ate mostly decapod larvae, adult Callianassa, and amphipods. The major food of the rest of the fish in the marshes and adjoining habitats consisted of amphipods, isopods, tanaids, polychaetes, cumaceans, copepods, dipterous larvae and pupae, and fish.

The tidal creeks in the Skagit River salt marsh of Washington's Puget Sound provide feeding grounds for large numbers of chum and chinook fry (200 to 800 fry per 100 m in April) (Congleton and Smith 1976). Their diets consist mostly of Corophium, harpacticoid copepods, and insect adults, larvae, and pupae. The high density of fry and the fact that most were collected with full stomachs supports the idea that this marsh serves as an important feeding area. In addition, Congleton (cited by Meyer 1979) has found that prey numbers increase in the marsh by late March before the epibenthic population in Skagit Bay has had a chance to build up. Thus, the marsh provides food for salmon juveniles during the period of time that food reserves in the bay are in short supply.

4.1.5 Uses of the Marsh

The most extensive work on the utilization of tidal marshes of the Pacific Northwest by various fish has been conducted by researchers at the Westwater Research Center, University of British Columbia in Vancouver. Most of the work has been done on the marsh creeks of the Fraser River Estuary. Only 32% of the Fraser's original wetland area has not been diked, and there is a great deal of interest in learning the value of the wetlands in order to protect them from further urban-industrial development. They are located on the Pacific Flyway and are therefore thought to be critically important to migratory waterfowl as well. In order to assess whether or not marshes act as rearing grounds for juvenile salmon, Westwater Research Center scientists studied fish diets, the utilization of the estuary, and habitat characteristics associated with high numbers of salmon. Most of the remainder of the discussion in this section is based on results reported in Westwater publications.

Chinook salmon spawn the length of the Fraser River as far as 1000 km upstream from the estuary. There are two types of chinook adults: smaller (~15 lb) red-fleshed fish that return from the ocean during the summer, and larger (~20 lb) white-fleshed fish that return from the ocean during the fall. White chinook spawn in the lower Fraser River while red chinook spawn in the upper river tributaries. Those spawning in the upper river produce fry which remain in the freshwater tributaries for either 3 months or one year. These fry spend little time in residence in salt marshes on their way to the ocean. However, the recently hatched white chinook fry of the lower river do use the marshes as rearing grounds (Levy and Northcote 1981). Levy and Northcote suggest that perhaps the difference in marsh utilization stems from the proximity of the spawning site to the estuary. Lower river chinook might have a higher rate of survival if they spend a period of time in the productive marsh waters. On the other hand, the chinooks from further up the river might benefit more from a longer residence time in the freshwater which would prepare them for their longer and more rigorous journey down the turbulent river.

The food web of the Fraser Delta is detritus based. Estuarine fish of the major arms of the Fraser River rely primarily on the benthos, i.e., secondary production. Most benthic invertebrates in turn feed on the detritus entering the estuary from terrestrial sources upstream in the watershed and from adjacent marshes. Marsh vegetation occurs along the islands, sloughs, and side channels, but the diked river banks lack large amounts of macrophytic vegetation. Northcote et al. (1979) felt that in temperate areas such as the Pacific Northwest feeding on the detritus itself would prove unreliable for the fish since the amount of detritus in the river and estuary varies seasonally. In tropical estuaries, where organic matter input is more constant, fish do feed mainly on detritus.

Northcote et al. (1979) analyzed the stomach contents of 21 species of fish collected over a one-year period on the mainstream lower Fraser River. The bulk of the diets of most of these fish came from the benthos. Chironomid larvae were a dominant food item for most of the resident species as well as for the juvenile salmon migrants. Terrestrial insect production was utilized only by the sockeye juveniles. As they migrated downstream, 90% (by weight or numbers) of their diet consisted of insects, mainly dipterans. In general, diets did not vary greatly seasonally. The fishes of this area utilize many different prey types, as do many north temperate fishes. Northcote et al. (1979) identified 21 prey classes. A given species may use up to 12 of the possible 21 classes, but an individual of that species restricts its prey to between 1.2 and 3.5 prey classes, probably a result of particular prey being most abundant in a localized area.

Table 15 ranks prey items of the dominant fishes of the Fraser's Woodward Island marsh tidal channels. Few salmon fry were found in the stomachs of fish predators in the tidal channels. Although fish are important in the diet of the large staghorn sculpin, salmon fry made up only a small proportion of their diet. Perhaps the marsh habitat is providing the young salmon with refuge from predators (Levy et al. 1979).

Levy et al. (1979) also related prey preference to predator size. The diet of the small pink salmon fry (34 mm mean length) collected in Fraser Marsh creeks consisted mostly of harpacticoids; chum fry (43 mm mean length) fed on both harpacticoid and insect pupae; and the largest fry, the Chinook (49 mm mean length), fed mostly on insect pupae.

Table 15. Relative importance of prey items of the dominant fishes of Woodward Island marsh channels. Ranking index = (frequency + volume percentage) percent occurrence. (modified from Levy et al. 1979).

Species	Order of relative importance*				
	1	2	3	4	5
Anadromous species					
Chinook smolt	a	g	h	c	b
Chum fry	h	f	i	c	g
Pink fry	f	h	i	c	g
Sockeye fry	g	h	i	b	c
Chinook fry	h	i	g	d	c
Longfin smelt	c	b	d	e	
Marine species					
Staghorn sculpin	c	e	b	a	d
Starry flounder	i	e	c	d	h
Pacific herring	b	c			
Freshwater Species					
Threespine stickleback	i	c	f	b	h
Prickly sculpin	b	e	i	c	d

*a = Fish.
b = Mysid shrimp (_Neomysis mercedis_).
c = Amphipod (_Anisogammarus confervicolus_).
d = Amphipod (_Corophium spinicorne_).
e = Isopod (_Gnorimosphaeroma oregonensis_).
f = Harpacticoid copepod.
g = Insect adult.
h = Insect pupa.
i = Insect larvae.

Occurrence, distribution, and residency patterns were obtained for the dominant fish species of the marsh tidal channels of Woodward Island in the Fraser River by Levy et al. (1979). Fish were trapped in these marsh channels when the tide began to ebb. Captured salmonids were marked with fluorescent grit and used in recapture studies for residency determinations. During 124 sampling days, 31 species of fish were collected. Juvenile salmon (pink, chum, and chinook) were taken between February and August but were most abundant between March and June. Five species occurred most consistently: longfin smelt, starry flounder, staghorn sculpin, threespine stickleback, and peamouth chub. Differences in maximum densities and timing of the seasonal peak occurred between channels.

Levy and Northcote (1981) were able to describe two fish communities occupying tidal channels of the Fraser marshes. Salmonids, sculpins, and starry flounders were associated with large tidal channels while sticklebacks and peamouth chubs occupied those tidal channels far into the marsh. Levy et al. (1979) found that distribution within the tidal channels also varied. Sticklebacks were concentrated far into the tidal channel whereas staghorn sculpins and starry flounders were most abundant near the mouth of the channel. The juvenile salmon were abundant at both ends of the channel. On ebbing tides the first of the salmon to emigrate from the tidal channels were the pink followed by the chum; the chinook remained in the channel the longest. Juvenile salmon, especially chinook, migrated also between channels.

Size of the juvenile salmon changed over the sampling period. Juvenile chinook showed the greatest increase in average size. Juvenile chum showed a small increase and juvenile pink showed no change.

Large numbers of juvenile chinook were recaptured after 1 month, while few pink salmon were recaptured. Recapture rates of juvenile chum salmon were intermediate (Levy et al. 1979). These recapture patterns, coupled with differential weight gains and the fact that the pink salmon were the first to leave the marsh tidal channels while the chinook remained the longest, indicate that juvenile pink salmon did not have extended marsh residency. On the other hand, chum and especially chinook salmon did.

The Fraser estuary contains 3,563 hectares (8,801 acres) of marsh. As discussed previously, juvenile chum and chinook salmon use these areas as rearing grounds. Hundreds of millions of these two species migrate down the river annually, and huge numbers of them are present in the marshes between March and June each year (Levy and Northcote 1981). In an effort to protect at least the most valuable parts of the marsh from further development and alteration, it is necessary to know what habitat characteristics provide for the richest and most used rearing grounds. Levy and Northcote (1981) found that consistently low catches of chinook fry were caught in certain marsh tidal channels. To determine which factors are important in attracting these fish to certain other marsh channels, Levy and Northcote (1981) measured 22 habitat characteristics. They found that 12 of these were significantly correlated with the number of chinook fry captured. The significant characteristics were: mouth width, station width (width of channel at sampling site), channel length, channel order (a ranking based on a series of 22 possible features), sub-channel length, mean angle of the channel bank, tidal slope, high tide height, tidal channel area, bank elevation, area of subtidal refugia, and the number of hours of tidal channel submergence prior to sampling. Many of these variables are highly correlated with each other.

It may be possible to pinpoint the best rearing ground areas using the above information. For example, bank elevation was inversely related to the catches of chinook fry, indicating that the fry are more likely to utilize low elevation marsh areas (Levy and Northcote 1981).

Chinook juveniles varied in size as well as in recapture rate in various marsh tidal channels in the estuary. During their survey, Levy and Northcote (1981) found that the tidal channels of Woodward Island were the site of the chinook having the largest size, the highest recapture rate, and the greatest abundance. Woodward Island also has the largest area of rearing habitat - the greatest marsh tidal channel and backwater area. It is therefore considered to be the most important rearing ground in that area of the estuary.

The Sixes and Rogue Rivers lack the marshes characteristic of the Fraser River estuary. In the Sixes River in Oregon, Reimers (1973) found that chinook reared in the estuary had a higher survival rate to the adult stage than did those reared outside the estuary. Shoaling occurs at the mouth of that estuary and inhibits flow to the ocean. This causes low shorelands to become inundated and, with the entrapment of nutrient-rich ocean water, increases the productivity of the estuary (Ratti 1979).

Opposite results were found in the Rogue River in Oregon. Twenty years ago, extensive shoaling occurred at the mouth of the Rogue River which encouraged juvenile chinook to spend considerable time rearing in the Rogue Estuary. Now, due to the jetties and channelization at the mouth, the chinook spend less time rearing there (Ratti 1979).

The effects of shoaling and associated increases in productivity in the Sixes may produce some of the same effects as occur in the Fraser. Perhaps the Sixes and the Fraser estuaries are best suited for those types of salmon which benefit from the use of such productive marsh areas and therefore spend time there on their journey to the ocean.

Questions that still need answering include: do those fish that reside in the estuary and its tidal marshes for some period of time have better survival rates than those that don't?; what are the populations of those areas of the tidal marshes not yet sampled?; what proportion of the migrating fry reside in the estuaries' marshes?; which of the river's stocks contribute to the estuary residents? If survival rates of estuary residents prove to be better than the others and if the marshes are found to be underutilized, then perhaps artificially produced fry could be given a better chance of survival by being released directly into the marsh rather than at sites further up the river (Levy and Northcote 1981).

4.2 MINERAL CYCLING IN THE MARSH

Mineral cycling in marshes of the Pacific Northwest has not been studied extensively. Gallagher and Kibby (1980) have measured fluxes of trace metals from soil to plants, but the turnover was not followed through the rest of the foodweb. Tjepkema and Evans (1976) have measured rates of nitrogen fixation in various plant species. Their studies focused on Baltic rush, but tests with tufted hairgrass, seaside plantain, and pickleweed also produced positive results. As a result, Tjepkema and Evans (1976) speculated that the association between nitrogen fixation and wetland plants is widespread. Although the bacteria were primarily associated with the rhizomes and large roots, neither their nature nor their exact location is known. We have no reason to believe that processes of nitrogen fixation by anaerobic bacteria and denitrification are proceeding any differently than in Atlantic coast marshes. The Pacific Northwest soils range from organic to mineral and are often saturated with saline water. Physical conditions are similar; rates, but not types, of processes probably differ.

Ammonification and nitrification likewise have not been evaluated, nor have various aspects of the phosphorus cycle. Data collected on gradients of phosphorus in Netarts Bay led us to believe the tidal marsh may be exporting phosphorus during the summer months. Similar measurements with nitrogen forms indicated an import from nearshore upwelling. The nitrogen, sulfur, and phosphorus cycles in marshes have been recently summarized by Whitney et al. (1981) and Wiebe et al. (1981) for Atlantic coast marshes. There is no reason to suspect that they are greatly different in marshes of the Pacific Northwest.

4.3 INTERACTIONS BETWEEN THE MARSH AND ADJACENT ECOSYSTEMS

One of the important features of tidal marshes is their ability to interact readily with adjacent ecosystems. This is made possible by the flooding and ebbing of the tidal waters which solubilize many substances and carry them to and from the marsh. Because water is dense, it can carry particulate materials ranging in size from microscopic detritus to Douglas-fir logs. The drift logs frequently strand and accumulate in many parts of the upper intertidal zone; they are a major feature of Pacific Northwest marshes. Because of their slow turnover rate and large mass, logs can be a long-term disruptive force as they move during major storm events.

Figure 18 represents a conceptual model of some of the major flows of energy and nutrients between coastal uplands, tidal marshes, tidal flats, and subtidal stream channels (the part of the estuary always containing water) in the Pacific Northwest. Like all conceptual models, it is a simplification of reality. We have not specifically shown a microbial compartment but have assumed they are ubiquitous. Documentation of the magnitude of fluxes is poor in all cases. Soil, water, and air zones are shown where appropriate; we depict the major biotic ecosystem components as being part of one or several of these zones. Interactions between each zone connected by water are shown with fused arrows to represent an easy exchange because of the water. Connections with coastal uplands are represented with closed arrows because exchanges are not as readily accomplished.

The principal direct exchanges between the coastal upland and the tidal flats and stream channels are through the movements of birds and mammals from the upland which feed in the lower zones on fish and invertebrates. Their excrement may represent a transport in either direction depending on where foraging and excreting occur. Between the upland and the tidal marsh similar exchange may occur with mammals. We have observed deer grazing some marsh plants such as arrow-grass, tufted hairgrass, and saltgrass. Upland birds may feed on marsh insects and marsh plant seeds, although documentation for these pathways is scanty for Pacific Northwest marshes. There is additional nutrient interaction associated with runoff of rainwater which carries dissolved nutrients and particulate matter from the higher elevation system to the next lower one. Direct exchanges also occur between uplands and tidal flats or stream channels when either directly abuts high ground. Where the topography is steep, direct interactions are more common.

Exchanges between tidal marsh and tidal flat are primarily in the form of DOC and POC from marsh plants and dissolved nutrients leaching from them and possibly from the soil. Tidal flats may export dissolved organic and inorganic compounds to the marsh on rising tides. Eelgrass and macroalgae perform the role of marsh plants at the tidal flat elevation. Invertebrates at the sediment-air and sediment-water interface and within the sediment play a much more important role on the flats than in the marsh. As in all ecosystems, fungi and bacteria play a pivotal role in the degradation process of whole plants to inorganic nutrients through POC and DOC.

Tidal flats probably interact more with the subtidal stream channels than with the marshes because tides connect them daily whereas tides carry materials to the marshes less frequently. Although the extent of this interaction has not been precisely quantified, there is a rather large export of eelgrass and, to a lesser extent, macroalgae from the tidal flats to the marsh (Gallagher et al. in press, b). The amount of eelgrass being exported to the marsh is greater than would be expected on the basis of normal tidal interactions; much of the eelgrass is broken loose from the beds by wave action during storms when tides are high in the fall. These events return a portion of the nutrients lost from the marsh by tidal exchange and, to an extent, close the cycling within the tidal flat/marsh complex and reduce the loss of energy- and

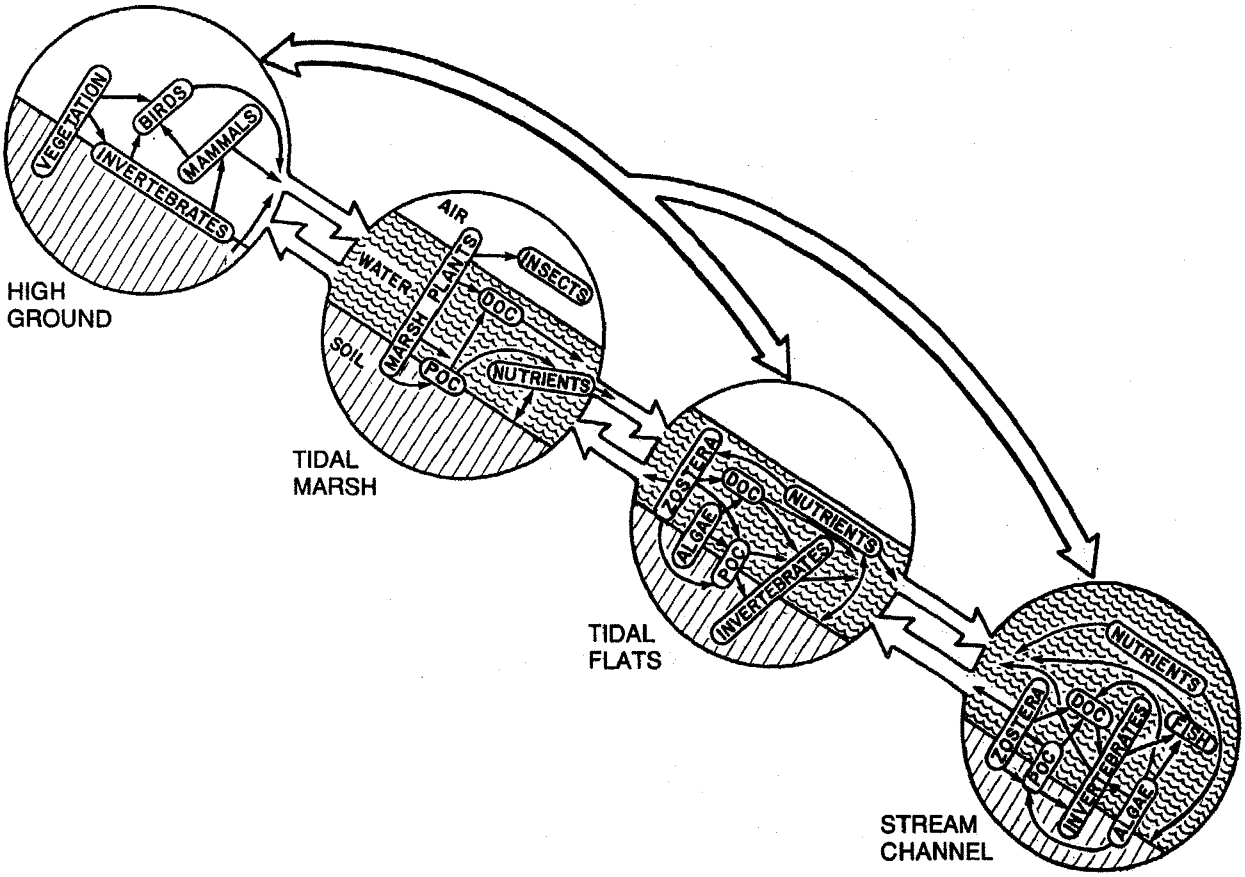


Figure 18. Conceptual model of energy or material flow between tidal marshes and other coastal ecosystems in the Pacific Northwest.

nutrient-rich compounds to the subtidal stream channels.

Exchanges from tidal flats to subtidal stream channels occur twice daily. The interactions involve the full spectrum of materials from nutrients to fish on their way to feed in tiny marsh creeks. Based on the previously discussed information from the British Columbia estuaries, it seems probable that the major role played by the wetlands in this coastal fisheries food web is to provide a nursery ground. That role is providing a sheltered habitat and producing POC and DOC which enter the stream channels to be utilized either by bacteria which are later consumed by invertebrates or directly by invertebrates which are food for various species of juvenile salmon. The residence time of the fish in the marsh-bordered estuary depends on the species.

These ecological interactions within the tidal marshes and between the marshes and adjacent ecosystems must be understood before wise decisions about wetlands management can be made. It is not enough just to know what organisms will be directly affected. The second and third order interactions may be the ones on which the decision should be based.

CHAPTER 5

MANAGEMENT

5.1 SENSITIVITY TO NATURAL AND CULTURAL PERTURBATIONS

There is concern that the true value of the tidal marsh to estuarine productivity will be realized too late - after many of the remaining marshlands are destroyed by landfills and development. Only recently have investigators begun to study marsh utilization by salmon and other fishes and assess quantitatively the significance of this habitat to western fish stocks. In the Fraser River estuary most of the fish populations are dependent on a relatively small array of benthic invertebrates, many of which are tidal marsh creek inhabitants (Northcote et al. 1979). Altering the species composition of the benthos with various land or water management projects which would change the supply or timing of detritus flow from upstream could be very detrimental to the food supply of the fishes downstream (Northcote et al. 1979).

Diking the marshes has been a long practiced method of increasing agricultral land but one which may decrease fisheries. Levy and Northcote (1981) concluded that juvenile salmon use the entire length of tidal channels and, therefore, that diking even a portion of a marsh area can significantly reduce the estuary's capacity as a rearing ground. Recall from Chapter 4 that the white-fleshed chinooks of the Fraser River reside in the estuary for a period of weeks or months before migrating to sea while the red-fleshed chinooks, originating further upstream, spend a longer time in the freshwater and are in the estuary only briefly. Estuarine populations of juveniles make an important contribution to the commercial and recreational catch of white-fleshed chinook and probably to some extent to that of the red-fleshed chinook (Levy and Northcote 1981). Levy and Northcote (1981) also suggest that it may be possible to use the resident juvenile population in the estuary as an index of the abundance of returning adult chinook stock.

Many marshes, diked or undiked, are grazed by domestic animals; these practices can also alter the system appreciably. Not only is plant production of detritus reduced, but nutrient cycles are altered and the soils physically compacted during grazing. The consequence of these alterations has not been thoroughly assessed in the Pacific Northwest. The role of the marsh in absorbing storm tides is little changed, and the grazed, undiked marsh continues to perform all its functions in the coastal zone although in a somewhat altered form.

Logging operations near the estuaries may also lead directly to damage when marshes are used as log storage areas. Escaped logs may end their journey on marshes; their effects may be long-lasting. (With decomposition half-lives measured in decades, logs can smother marsh plants and block creek channels thereby changing the hydrology of the systems. Figure 19 shows a creek filling in as a result of the channel being blocked by a log. As the siltation process continues here, the Lyngbye's sedge marsh will probably completely close the gap between the two sides of the former channel.

Marshes tend to be very sensitive; even paths made by scientists traveling to study sites may be visible several years after the study ends. Not only are the plant stems themselves crushed, but after several trips, the rhizome mat in the soft

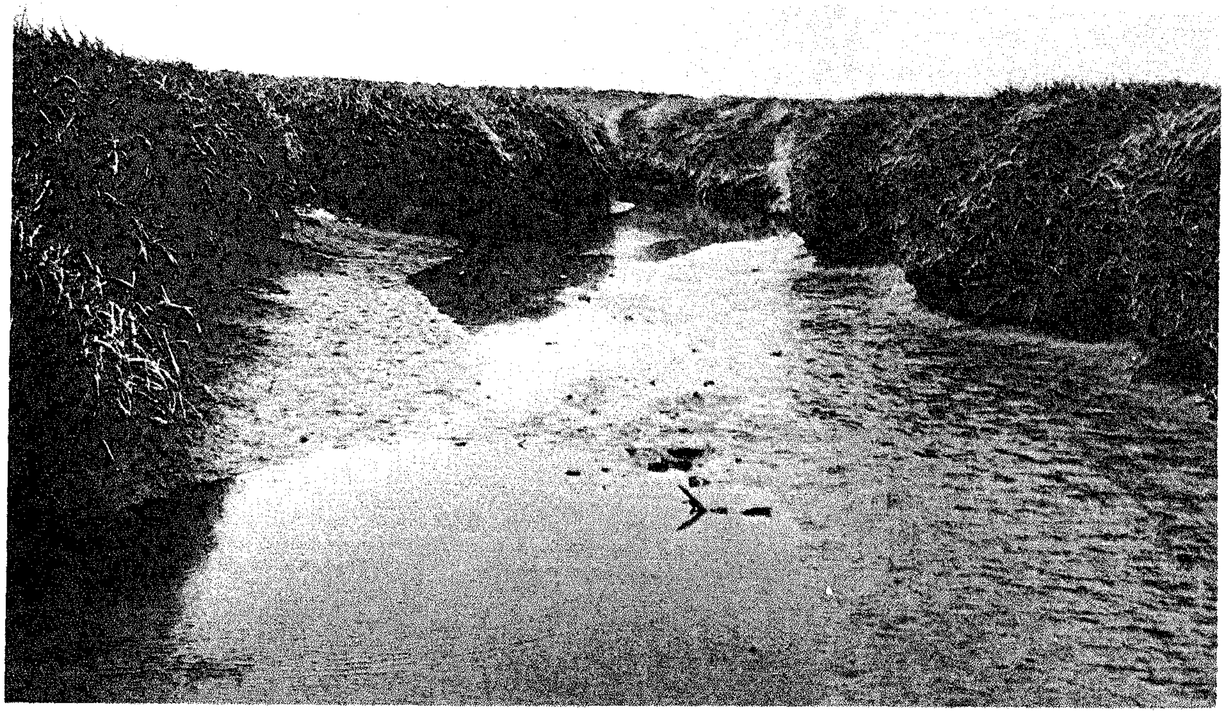


Figure 19. Lyngbye's sedge marsh invading a mudflat created by a log blocking a marsh creek.

sediments is damaged. Reinvasion of these damaged areas appears to be surprisingly slow. In the lower edges of the sedge marshes, the primary colonizer may be arrow-grass which is also a common invader on tidal flats adjacent to low silty marshes.

5.2 HISTORICAL MANAGEMENT APPROACH

Historically, man's greatest impact on Pacific Northwest tidal marshes has been caused by diking in an effort to expand land usable for agriculture. Salt marshes were diked and drained by the earliest white settlers and used as crop and pasture lands. Almost all old, high marsh areas of Oregon have been diked (Jefferson 1975). Today many of these areas are still used for grazing (Figure 20), and marsh hay is still cut. Once the marsh is diked, the soils compact and become aerobic; the soil salinity gradually decreases. The plant community slowly changes from a halophytic plant community to a damp meadow community because of the soil changes, different drainage patterns, and grazing (Jefferson 1975; Mitchell 1981).

Salt marshes have been altered by filling and spoil disposal as well. In comparison to the relatively limited extent of the coastal estuaries, a tremendous acreage of intertidal area has been filled in the Pacific Northwest. According to the U.S. Army Corps of Engineers (USACE 1976, cited by Proctor et al. 1980), 1,554 ha (3,840 acres) in Grays Harbor have been used for dredge material disposal. A total of 283 ha (700 acres) in the Columbia River Estuary have been filled (Seaman 1977, cited by Proctor et al. 1980). A large percentage of the original marshland of the Skagit River delta in Puget Sound has been destroyed or altered. Today less than 20% of these marshes remain (Congleton and Smith 1976). About 40% (2,509 ha, 6,200 acres) of emergent marsh of Willapa Bay has been altered by diking and filling (USACE 1976, cited by Proctor et al. 1980). Hoffnagle and Olson (1974) estimated that 90% of the

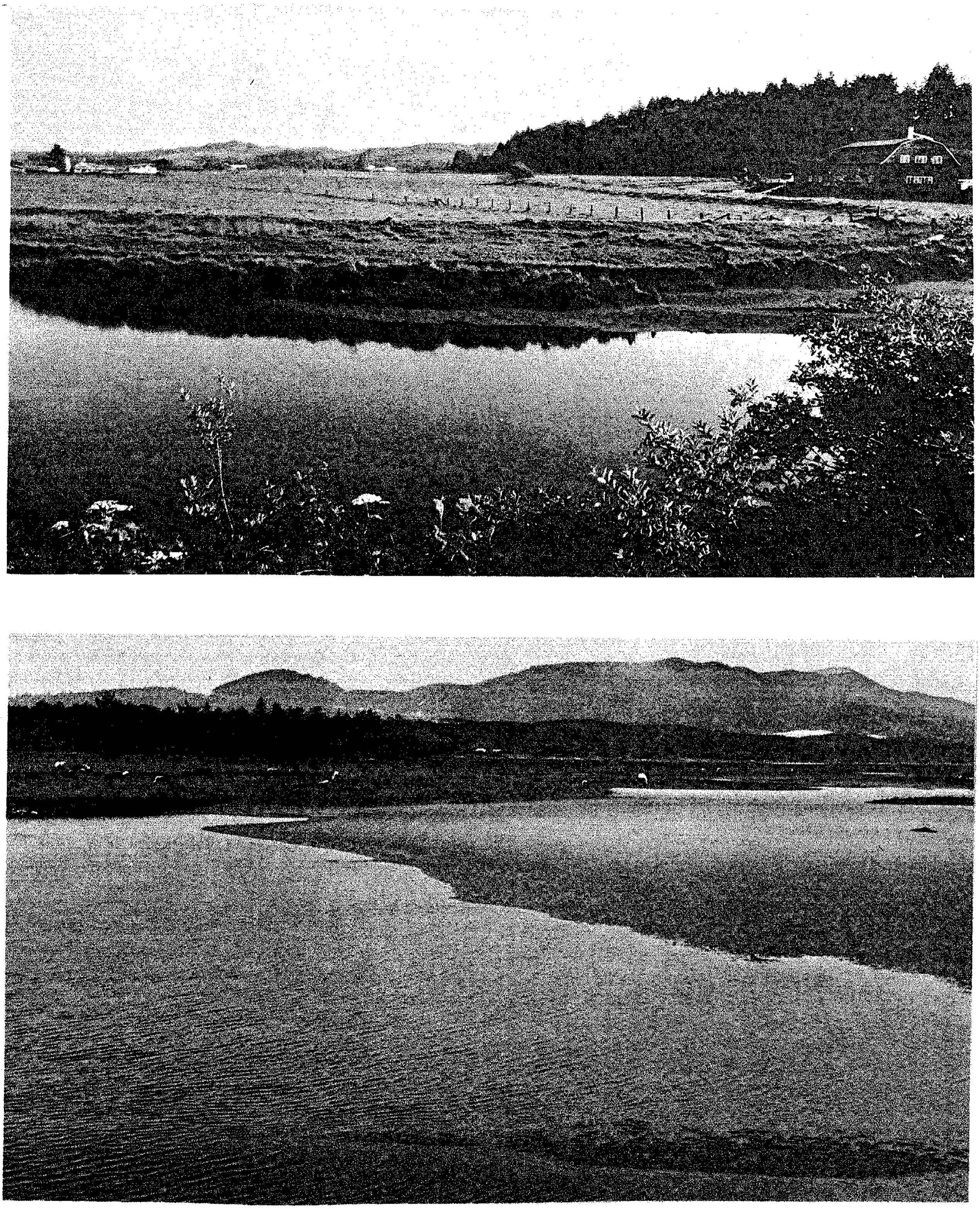


Figure 20. Diked (upper) and undiked (lower) marshlands which are being used for pasture.

original salt marsh of Coos Bay has been altered by diking and filling. Landfills in other Oregon estuaries are summarized in Table 16.

Logging practices have also taken their toll on the Northwest marshes. Hoffnagle and Olson (1974) have described the effects of logging on the Coos Bay salt marshes. Erosion due to clear cutting and slash burning increased sedimentation in the bay; this in turn led to increased dredging and the dumping of dredged material on marshes. Logging also results in the accumulation of logs and woody debris.

Only a very small percentage of the Northwest's original marshes remain unchanged, especially in the highly developed areas. The slow, natural progradation of some of the marshes cannot make up for the historical destruction of this valuable resource.

While wetlands have been perturbed, altered, and destroyed since the area was first settled, the history of their protection is much shorter. Bean (1978) summarized the role of the Federal Government in wetland protection. In cooperation with the States, the Federal Government began acquiring wetlands in 1929 with the Migratory Bird Conservation Act. About this same time, however, the Federal Government started a huge hydroelectric development program with the enactment of the Federal Power Act of 1920. This, along with the Flood Control Act of 1936, essentially cancelled the wetlands preservation benefits of the Migratory Bird Conservation Act. In an effort to reduce the adverse effects of the 1920 and 1936 Acts on wildlife, the Fish and Wildlife Coordination Act, originally passed by Congress in 1934, was amended in 1958 to include the mitigation concept. In essence, this meant that if public hunting and fishing were disturbed due to a Federal water development project, private lands of similar recreational quality must be purchased to replace those lost.

Until the late 1960's the Federal Government ignored private activities affecting wetlands. With the passage of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), the Federal Government became the principal regulator of the development of wetlands. Under Section 404 of these Amendments, the Environmental Protection Agency and the U.S. Army Corps of Engineers have the responsibility of setting wetland boundaries and protecting navigable waters by protecting some wetlands. Permits must be issued by the U.S. Army Corps of Engineers for the discharge of dredge or fill

Table 16. Landfills on lands lying between the line of ordinary high water and the line of ordinary low water in selected Oregon estuaries (modified from Percy et al. 1974).

Estuary	Acres	Use
Alsea	24.8	Marine oriented/ recreation
Nehalem	7.3	Residential/ recreation
Nestucca	0.7	Erosion control for residential property
Salmon	0.1	Parking area/boat launch
Sandlake	3.0	Diked, agricultural
Siuslaw	40.6	Marine-oriented industry
Tillamook	102.1	Industry
Umpqua	97.5	Marina and harbor/ marine-oriented deepwater navigation and industry
Yaquina (below Toledo)	202.1	Marine-oriented deepwater navigation and industry
TOTAL	478.2	

material onto wetlands contiguous with navigable waters or into the waters themselves. The Coastal Zone Management Act has made Federal funds available to encourage coastal States to develop management programs for their coastal zones and resources. The State may then be eligible for Federal grants-in-aid to put their management programs into effect. One of the remaining critical problems in tidal marsh management is locating the upland marsh boundaries as indicated in Section 404 of Public Law 92-500.

5.3 UPLAND MARSH BOUNDARIES

It has been realized in recent years that the protection of wetland ecosystems is of paramount importance because they are very productive, are used by fish as rearing and feeding grounds, serve as storm buffers, and improve water quality of adjacent stream channels. In order to protect a wetland from intrusions such as filling, diking, draining, and pollution, the limits of that wetland must first be defined. Herein lies the difficult technical problem of quantifying the legal definition.

In the United States, regulations set forth by the U.S. Army Corps of Engineers define wetlands as:

> . . . areas that are inundated or saturated by surface or ground water of a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (USACE 1981)

In the field, this definition alone becomes inadequate. In those situations where the transition from the wetland to the upland is abrupt, it is relatively easy to determine the upper limit of the marsh since the change from wetland soils and vegetation to upland types occurs in a short distance (Figure 21). However, the problem of clear determination of the upper limit becomes very difficult in areas where the grade of the slope is low and the transition zone from undisputed wetland to upland is gradual (Figure 21). In this case the answer is not easily defined, and the resolution becomes a policy decision rather than a scientific determination.

The U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency have the responsibility to develop guidelines by which wetland boundaries may be delineated for determining where permits are required. Several approaches have been proposed and taken by various investigators and agencies to delineate wetlands. Some states define intertidal wetlands with respect to a tidal datum, e.g., mean low water (Wass and Wright 1969; Virginia Code, Sec. 62. 1-13,2). After an investigation of eight coastal marsh sites, the National Oceanic and Atmospheric Administration (NOAA 1975) suggested the upper limit of the marsh be defined at 0.76 m (2.5 ft) above mean high water (MHW). With further study this criterion was found to be satisfactory only for the Atlantic and gulf coasts but unsatisfactory for the West coast, where the ecotone spanned elevations of up to one meter. NOAA therefore set the upper marsh limit as being the average of the upper and lower limits of the transition zone, which in turn was based on floristic composition.

Floristic criteria involve basing the upper wetland limits on the presence of certain species. Frenkel et al. (1978) identified the transition zone in Oregon by a strong dominance of Pacific silverweed and the presence of *Achillea millefolium*, *Angelica lucida*, *Aster subspicatus*, *Oenanthe sarmentosa*, marsh clover, and *Vicia gigantea*. Some statutes specify a list of indicator plants which may be used to identify a wetland (New York Environmental Conservation Law, Sec. 25-0103, cited by Lagna 1975). Frenkel et al. (1981) used a combination of floristic and vegetational (plant coverage) criteria to establish lists of upland and wetland plants and to develop a quantitative measure integrating floristic and vegetational data. They could thus determine upland limits by shifts in plant community structure.

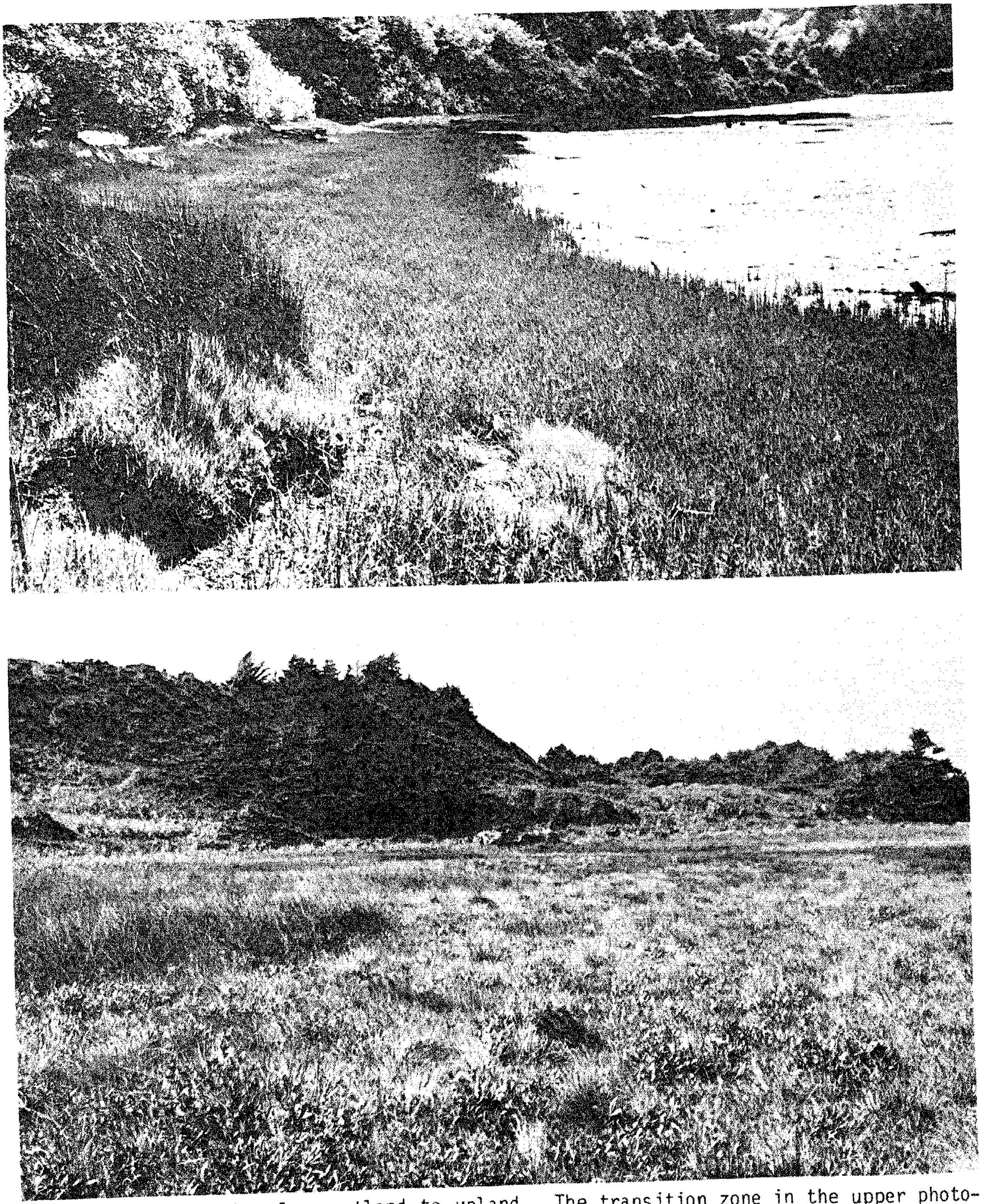


Figure 21. Transition from wetland to upland. The transition zone in the upper photograph is sharp and the transition from low silty marsh to upland takes place in a few meters. The left hand side of the lower photograph depicts a gradual transition from a low sandy marsh to upland. The transition is spread over 20-30 m.

Remote sensing techniques have also been proposed as a means of defining wetlands for jurisdictional purposes (Reimold et al. 1972). Different species of plants and mixed plant communities have distinct signatures on color infrared film; hence the color patterns can be used for obtaining a vegetation map (provided it is carefully checked on the ground). In cases where the transition to upland is steep, good wetland maps can be prepared.

Physical criteria such as soil salinity and soil moisture are possible criteria on which to base the definition of wetland limits. Salinity, however, varies diurnally, seasonally, and with depth and distance from the estuary mouth. Salinity would therefore not provide consistent data. Soil moisture, used in the U.S. Army Corps of Engineers definition of a wetland, would seem a likely method for determining wetland limits. However, making the decision as to whether an area is wetland or upland cannot be based on soil moisture measurements made at a single point in time. High temporal variability caused by precipitation and tidal fluctuations would have to be overcome by taking many observations; seasonal data might be required, and frequency/duration values for selected depths in the marsh computed (Lewis and Liverman 1979). The necessity of such a long-term study would be impractical for the purpose of permit evaluation.

Seliskar (1981) investigated the possibility of using plant morphology as an aid in setting wetland limits. She found morphological and anatomical differences within species depending on the moisture regime under which the plants were growing in the field. Plant height changes, degree of branching and flowering, and amount of aerenchymous (air conducting) tissue varied with soil moisture content. Root distribution within the soil also varied with soil moisture. A large percentage ($\geq$65%) of root and rhizome biomass in the upper 10 cm of a soil core served as an indicator of high soil moisture for four salt marsh plant species tested (Seliskar, in press). These various changes are most useful after a gross limit has been set and a more precise delineation is needed.

The USACE Waterways Experiment Station's Wetlands Group is currently recommending a three-faceted approach to determining wetland status involving: hydric soil characteristics, hydrologic indicators, and wetlands vegetation (Huffman 1981). The hydric soils criteria involve the color of the soil which is an indicator of the oxidation-reduction status of some of the soil minerals. A chroma (strength of color) of 1 or less in the root zone or a chroma of 2 with mottles of different color is taken as an indicator of hydric soils. Hydrologic indicators are evidence of high water in the area. These may vary from tidal water level recordings to drift lines and ice scour marks. The third and final criteria is the presence of vegetation recognized as being typical of wetlands. Although this method works well in most cases, none of the methods suggested has yet been refined to the point of working satisfactorily in all field situations.

5.4 CURRENT MANAGEMENT PRACTICES AND FUTURE PROSPECTS

The mitigation concept has evolved to mitigation rather than replacement in recent years. Instead of simply purchasing lands of similar quality to those being lost to development, areas that were once productive wetlands are being restored and new wetland habitats are being created on dredge materials. For example, a 3.2 ha (8 acres) dredged material island, Miller Sands, in the Columbia River Estuary (39 km or 24 mi from the mouth) has been planted with marsh plants (sedge, bulrush, *Juncus effusus*, *Carex obnupta*, and tufted hairgrass) (Kirby 1978; McVay et al. 1980).

Oregon has one of the most rigorous fill and removal laws in the nation. The Oregon Land-Use Program is based on a series of legally enforceable "goals." A requirement of their Estuarine Resources Goal states that:

> When dredge or fill activities are permitted in intertidal or tidal marsh areas, their effects shall be mitigated by creation or restoration of another area of similar biological

> potential to ensure that the integrity of the estuarine ecosystem is maintained. (Oregon LCDC 1976)

Guidelines to the above requirement (Oregon LCDC 1976) state that, if possible, the mitigation site should be near the dredge or fill site in order to be the most similar ecologically. If this is not possible, then other areas with similar (in order of importance) salinity, tidal exposure and elevation, substrate, current velocity, orientation to solar radiation, and slope characteristics should be selected for mitigation. If neither of these aforementioned mitigation site criteria can be met, then the restoration of areas or resources of the greatest scarcity compared to past abundance must be undertaken. Dredge material islands, diked marshes and those wetlands separated from circulation by causeways, or other fills are suggested as potential mitigation sites. LaRoe (1978) stated that the Estuarine Resources Goal was carefully conceived and worded and is intended to prevent any further net loss of intertidal habitats in Oregon.

As an example, the mitigation requirement was first tested when the city of North Bend requested a permit to fill a 13 ha (32 acres) sandy bottom area of Coos Bay. The mitigation site chosen was a third priority type - diked marsh in a different part of the estuary. The question of how much marsh to mitigate for 13 hectares (32 acres) of sandy bottom was a difficult problem (LaRoe 1978). A "submerged time equivalence" method to relate surface area and time submerged was developed at Oregon State University. As a result, 26 to 28 ha (65 to 70 acres) of diked marsh was determined as the proper area to be restored to mitigate the loss of 13 ha (32 acres) of sandy bottom (LaRoe 1978). Taylor and Frenkel (1979) predicted that approximately 12% of the mitigation site, that lying below 1.4 m (4.6 ft) elevation, would become tidal mudflat. They expected that in 40% of the mitigation site, the area between the elevations of 1.4 and 2.4 m (4.6 and 7.8 ft), the diked marsh vegetation would be replaced by those species normally found on silty substrates. The area above 2.4 m (7.8 ft) (48% of the site) was thought to be suitable for the development of high salt marsh. To date, neither the filling nor the creation has taken place.

Perhaps the most powerful tool to have recently received widespread acceptance in solving problems relating to tidal marsh use is the mitigation procedure. Although the price of rehabilitating wetlands degraded in a previous era or converting upland to marsh is high, the economic value of being able to destroy certain wetland sites during estuarine resource development is immense, and high mitigation cost can usually be justified economically. Judicious application of this procedure makes it possible to continue economic growth in the coastal zone without destroying the natural resources which make that economic development possible and which drew people to the coasts in the first place.

CHAPTER 6

SUMMARY AND COMPARISONS

Tidal marshes of the Pacific Northwest do not form a continuous band parallel to the coast as do the wetlands along much of the Atlantic and gulf coasts. These discontinuous marshes may develop on the intertidal flood plains of estuaries and may extend miles inland. Alternatively they may arise along the quiet borders of sandspits which have enclosed embayments along the rocky coast. Tidal marshes arising in riverine systems tend to be fresher than those behind sand bars since they are fed by rivers or streams which extend well into the Coastal Range or even into the Cascade Mountains.

Snowmelt from the Cascades produces a large freshwater pulse into the Columbia River and Puget Sound which may last several months in the spring. In the Columbia and many other rivers, the storage capacity of hydroelectric dams has severely curtailed freshwater runoff during snowmelt or periods of high rainfall. Where pulses of freshwater do occur, marsh soil salinities may be seasonally depressed thus allowing seeds of plants otherwise inhibited by saline conditions to germinate. Adult plants may also be influenced when salinity stress is reduced during the early season growth. This may result in greater primary productivity than would occur without the freshwater. Those marshes behind the sandspits developed on bay mouth bars, on the other hand, are often exposed to salinities only slightly lower than the coastal water since often only small freshwater sources are included in the drainage basin.

The substrates on which Pacific Northwest marsh fauna and flora depend vary from very sandy to primarily silt and clay. More mature marshes have built their own substrate of peat. In the Pacific Northwest, as along the Atlantic and gulf coasts, the addition of new sediments to the wetlands has been decreased by upriver dams, channelization, and diking of river banks. Sediments are often trapped in upstream reservoirs or sent offshore rather than being trapped in the coastal zone. In those areas where spring freshets bring new sediments to the marshes, the nutrient cycles which take place in the decaying peat are subsidized by the seasonal input of nutrients. The coastal upwelling phenomenon, which is not found on the Atlantic and gulf coasts, provides a mechanism for bringing nutrients in deep coastal water back to the Pacific estuaries via flood tides.

Like the Atlantic coast, the tides of the Pacific Northwest have two highs and lows daily, but unlike those in the east, they are vastly unequal in height. This complex pattern of flooding produces a high diversity of environmental gradients in moisture and salinity that affects both plant and animal distribution. Along the gulf coast where tides are diurnal and of relatively low amplitude, wind and storm tide-related water surges play a much greater role in the hydrology of the extensive, nearly flat marshes than they do in the Pacific Northwest.

Like the New England marshes, the saline marshes of the Pacific Northwest have a high angiosperm diversity compared to the extensive monospecific stands of gulf coast and Atlantic coast marshes south of Cape Cod. The upland border transitions in the Pacific Northwest tend to be sharper than those of many other coastal areas because of the sharp topographic relief in the region. Few studies have defined the moisture tolerance of tidal species in the region, and there are still some problems with setting the upper boundary of the marsh. Macroalgae are prominent in the occasional tidal pools on the marsh surface and permanent pools in the streams.

Microfloral assemblages of the region have not been as well studied as those in the marshes of southern California or the Atlantic and gulf coasts. There are, however, substantial algal populations on both the marsh surface and the bare banks bordering the creeks. Fungal and bacterial populations in the soil or in the dead plants have not been studied, but decomposition rate experiments indicate processes involving these organisms are as rapid as in the Southeast Atlantic coastal tidal marshes.

Faunal components on the marsh surface are dominated by insects on the marsh plants and by amphipods in the eelgrass wrack community. Notably absent are the fiddler crabs and snails common in the marshes of the Mid-Atlantic and Southeast. Bird and mammal utilization of the Pacific Northwest wetlands is extensive in some areas, but perhaps the most important food web trophic linkages with vertebrates occur with the fishes in the tidal creeks. Data from southwestern Canada document the use of tidal marsh habitats by juveniles of commercially important salmonids. Juvenile salmonids and other fish feed on organisms such as harpacticoid copepods, which in turn depend on marsh detritus for their sustenance. The residence time of the numerous species of salmonids is variable and depends on species and estuarine conditions. In addition to the salmonids, there are a number of other important forage fish which are found as temporary or permanent residents of the tidal marsh streams.

Energy and materials which flow between the marsh and upland ecosystems are dependent on animal migration and water flow from the uplands. Adjacent ecosystems at lower elevations, such as the mud and sand flats and subtidal estuarine channels, can additionally interact via tidal waters which can carry materials in both directions. Eelgrass beds can influence the marsh by acting as filters for nutrients coming into the wetlands from coastal upwelling or by trapping nutrients leaching from decomposing marsh grasses. Further, the seagrasses may be carried by the tides to the marsh where they decompose, thereby cycling the nutrients between tidal marsh and adjacent seagrass beds.

Historically, tidal marsh management in the Pacific Northwest has involved the exploitation of the wetlands for agricultural purposes. The high intertidal wetlands have been grazed and many of the lower wetland habitats have been "reclaimed" by the construction of dikes. These "reclaimed" lands were primarily used for pasture and hay crops in the dairy regions of the coast. Recently the value of these coastal wetlands has been recognized, and laws protecting them from being filled or annexed to the adjacent upland have been enacted. Mitigation procedures have become popular in recent years; restoration of damaged marsh or the creation of new ones on dredged material has frequently been the proposed solution when coastal development requires the destruction or alteration of existing wetlands.

The challenges for scientists, managers, and developers in the coming years are complex and difficult. How can we have maximum economic growth in the coastal zone without destroying the ecological and aesthetic base which inspired that development? What is the necessary areal extent of the various components necessary to sustain the natural and anthropogenic systems? What is the best spatial distribution of marsh, mudflat, seagrass bed, and stream channel for a particular site? How can we manage the marsh-estuarine complex to maximize productivity? The solution to these problems involves not only the development of sound management plans, but also the establishment of a valid scientific base on which to make these plans. Perhaps the greatest danger is that we will bypass the latter in our rush to devise the former.

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16. Abstract (Limit: 200 words)

Tidal marshes of the Pacific Northwest develop (1) on the fringes of estuaries of rivers which empty more or less directly into the ocean or Puget Sound and (2) behind baymouth bars which form between adjacent headlands on the rocky coast.

Floristically these wetlands are more complex than marshes of equivalent salinity along the gulf, Southeast and Mid-Atlantic coasts. Pacific Northwest marshes resemble more closely those of northern California and parts of New England. Primary productivity ranges widely as do rates of plant decomposition. Detritus appears to fuel a productive food web, the best documented of which involves salmonids feeding in the marsh creeks. Except for insects, macrofauna are not common on the marsh surface. A conceptual model of functional groups within the marsh, and a model depicting interactions between the marshes and adjacent ecosystems are presented.

To date fewer quantitative ecological studies have been done on these wetlands than on those in parts of California or the gulf and Atlantic coasts. This situation is rapidly changing and the emerging picture is that Pacific Northwest marshes are similar in function to those more intensively studied. Organisms and relative magnitudes of the fluxes are different, but processes are the same.

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