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Estuarine Science, Management, and Restoration

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Estuaries—are they inland extensions of the sea or downstream extensions of a watershed's aquatic ecosystem? An oceanographer might find the first definition more satisfying, while a stream ecologist might prefer the latter. They are likely to agree, however, that estuaries are unique transition ecosystems—complex, dynamic, productive, and in many ways different from either the adjacent ocean or the river upstream.

Estuaries provide many goods and services to humans and other organisms. Examples include fish and shellfish production, water purification, shoreline stabilization, wildlife habitat, and recreational opportunities.

Estuaries are home to an incredible array of plants and animals, many so small and abundant that there may be billions in a single glass of bay water. Estuaries play key roles in the life cycles of important marine and anadromous aquatic species—crab, salmon, and herring, to name a few—as well as migratory waterfowl and shorebirds.

With a twice-daily ebb and flood of the tide, salt water and fresh water mixing, and rapid fluctuations in temperature and salinity, estuaries can be difficult places to live. But the plants and animals that thrive there have developed remarkable adaptations to these difficult conditions—adaptations for feeding,

In this chapter you'll learn:

- What an estuary is
- Why estuaries are important
- How physical and biological processes drive these ecosystems
- How Oregon's estuaries function and how they are used and managed
- How to assess estuarine health and develop a restoration action plan
- How to design, construct, and monitor estuary restoration projects

reproducing, rearing their young, avoiding predators, and regulating their bodies' temperature and salt concentration. Estuarine ecosystems and their inhabitants thus are by nature resilient. At the same time, however, past changes and present threats make them highly vulnerable.

Human history and economic development are intimately linked to estuaries. Estuaries provide abundant, easy-to-access fish and shellfish. We build cities on their shores and ports in their sheltered harbors. We come to the sea to breathe the salt air and be renewed.

See Section II, Chapters 4, 5, 6, and 9 for information related to this chapter.

Some of the ways we use estuaries change these ecosystems, often significantly. We selectively harvest plants and animals. We consciously or inadvertently introduce nonnative organisms, including pest species. We dredge navigation channels, build jetties, fill tidelands, dike salt marshes, dump wastes, and more. Although some of these uses have economic and other benefits, they often adversely affect the natural goods and services that estuaries provide to society.

Over the past several decades, we have come to understand the value of the goods and services healthy estuaries provide. We also have learned it is not too late to protect what remains and to restore damaged areas to health. All along the Oregon coast, estuarine habitats are being protected, development is being directed to areas where adverse impacts can be avoided or minimized, and new pollution controls are being put in place.

Improving damaged and degraded estuaries is the next logical step. Local watershed councils, land trusts, other groups, and state and federal biologists are surveying and remapping Oregon's estuaries, identifying potential restoration actions, and examining pollution sources and other problems. They're using lessons learned from existing restoration projects to design and evaluate new projects.

Nevertheless, both old and new threats to Oregon's estuaries remain. An example of an emerging threat is invasion by green crab and other nonnative nuisance species. Restoration of Oregon estuaries has started, but much remains to be done.

What is an estuary?

es·tu·ar·y (es´-chew-wer´-ee), n. **1.** that part of the mouth or lower course of a river in which the river's current meets the sea's tide. **2.** an arm or inlet of the sea at the lower end of a river. *(Random House Unabridged Dictionary,* 1993)

The dictionary provides a simple, intuitive definition of an estuary. But it leaves many questions unanswered. For example, how far upriver does an estuary extend? Is a lagoon with little freshwater inflow an estuary? Why are these ecosystems so important and highly regulated? What is the role of estuaries in the life cycle of Pacific salmon and other species of commercial, recreational, or ecological importance? More technical definitions begin to answer these questions.

A classic, often-quoted scientific definition advanced by oceanographer Donald Pritchard in 1967 is that an estuary is *"a semi-enclosed coastal body of water which has a free connection with the open sea and, within which, seawater mixes and usually is measurably diluted with freshwater from land runoff."*

Oregon, in its statewide planning goal for estuaries (Goal 16–Estuarine Resources), adopted a very similar, but expanded, definition, saying that an estuary *"includes estuarine water, tidelands, tidal marshes, and submerged lands. Estuaries extend upstream to the head of tidewater, except for the Columbia River estuary, which by definition extends to the western edge of Puget Island."* We use this definition in this chapter.

Why we need healthy estuaries

Healthy estuaries provide important habitats for many species we value such as salmon, herring, flounder, crabs, oysters, clams, wading birds, ducks, geese, shorebirds, and harbor seals (Figure 1). Deep channels, sloughs, tidal flats, salt marshes, eelgrass beds, and other habitats provide food, shelter, resting areas, and nursery grounds. These habitats also are home to thousands of lesser known species that are vital to healthy estuarine ecosystems—burrowing ghost shrimp; strange-looking polychaete worms; and microscopic copepods, molluscs, and other planktonic species.

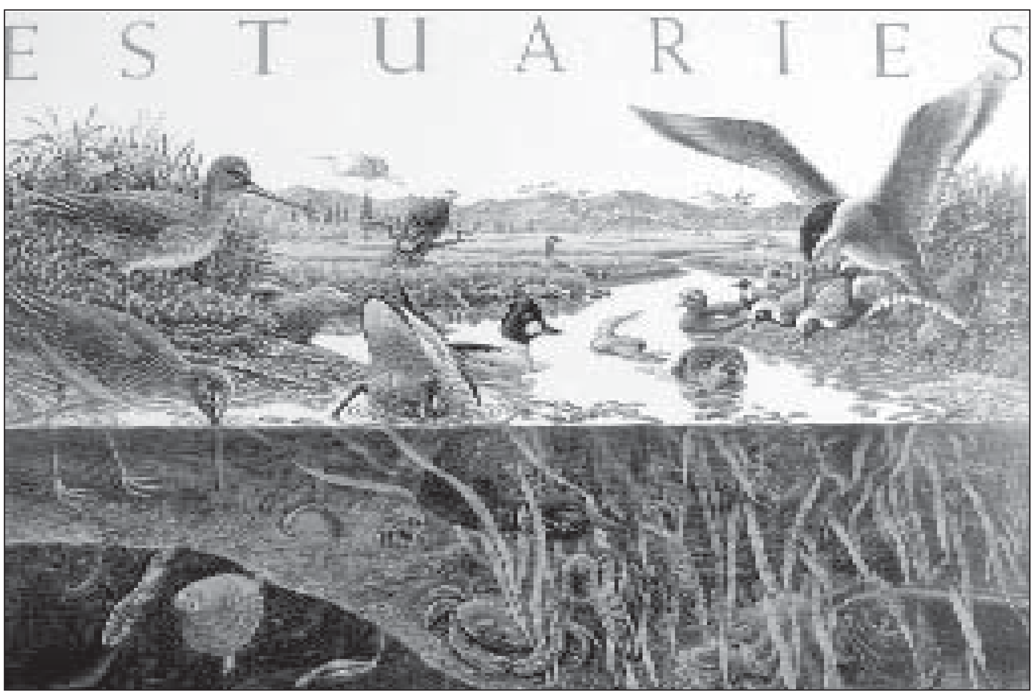


***Figure 1.**—Pacific Northwest estuaries support a great diversity of plants and animals. (Artwork by Larry Duke, courtesy of the Washington State Department of Ecology)*

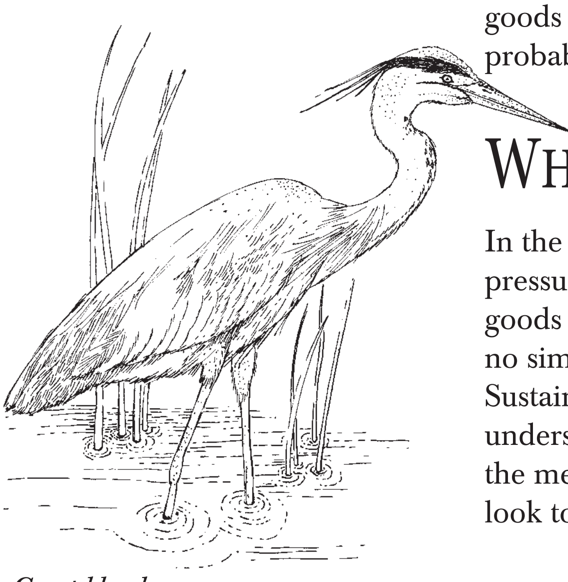
One reason for the diversity and abundance of animal life in estuaries is their high *primary productivity.* In other words, they grow a prodigious amount of plant material that serves as food. Salt marsh grasses and sedges, thick beds of filamentous algae, kelp, eelgrass, and literally billions of single-celled diatoms and other microscopic plants called *phytoplankton* all are products of the estuary food factory.

Just how productive are estuaries? No one knows for sure, but scientists studying salt marshes in Nehalem Bay provide some hints. They found that just 1 square meter of Lyngby's sedge *(Carex lyngbyei),* one of the most abundant tidal marsh species, produces 1,850 grams of carbon each year–about 4 pounds. That scales up to more than 8 tons per acre per year.

Nearly all of this material dies each fall and is recycled in the marsh or transported into estuarine waters. Microscopic bacteria break down this plant debris, contributing to the rich brew we call *detritus*. Detritus, transported by the tide throughout the estuary and into sloughs and tidal creeks, is the foundation of life in estuarine ecosystems.

Estuaries also help *keep water clean*. They use excess nutrients for plant growth and neutralize pollutants. These water-quality services would cost taxpayers millions of dollars using modern pollution-control technology, yet estuaries perform them for free if their assimilative capacity is not overwhelmed. Fringing marshes and other estuarine wetlands, like their upland counterparts, also *slow flood waters* and *stabilize the shore* to prevent erosion.

Finally, estuaries are vital for the *economic and recreational services* they provide–transportation, commerce, commercial and recreational fishing, clamming, waterfowl hunting, birding, boating, sailing, sight-seeing, and simple enjoyment of nature. Among the goods and services estuaries provide, these are the most visible and probably the most valuable in dollar terms.


Great blue heron

WHAT CAN WE DO?

In the face of continuing population growth and development pressures, how can we sustain or even increase the flow of estuarine goods and services for ourselves and future generations? There are no simple answers, the task is not small, and no one can do it alone. Sustaining healthy estuaries over the long term requires an understanding of existing problems and challenges, clear goals and the means to achieve them, the ability to learn from the past and look to the future, and the will to make decisions.

For Oregon's estuaries, we need to:

- Protect and conserve the remaining critical estuarine habitat.
- Restore former or degraded estuarine habitats where feasible.
- Link estuarine restoration actions to upland and upstream restoration and enhancement efforts for a whole-watershed approach.
- Monitor water quality, clean up existing pollution, and prevent new pollution that cannot be readily assimilated.
- Avoid the inadvertent introduction of harmful plants and animals.
- Work simultaneously from the bottom up (the community level) and the top down (through state and federal assistance) to make sure our efforts are feasible and effective both locally and regionally.
- Incorporate both local knowledge and the best available scientific information into our planning, decision making, and projects.
- Conduct necessary research to improve understanding of estuarine ecosystems and their relationships to marine and freshwater systems.

Oregon's estuaries

With 22 "major" estuaries (Figure 2) and many smaller ones, Oregon would seem to be estuary-rich. Actually, quite the opposite is true. According to a National Oceanic and Atmospheric Administration inventory, Oregon has only about 0.6 percent of the estuarine acreage in the lower 48 states (210 square miles of more than 35,000 nationally).

The Columbia River estuary constitutes more than half of this area, so the remaining Oregon estuaries are comparatively small. Except for the Umpqua and Rogue, the watersheds they drain also are small, reflecting the geology and topography of the mountainous coastal zone.

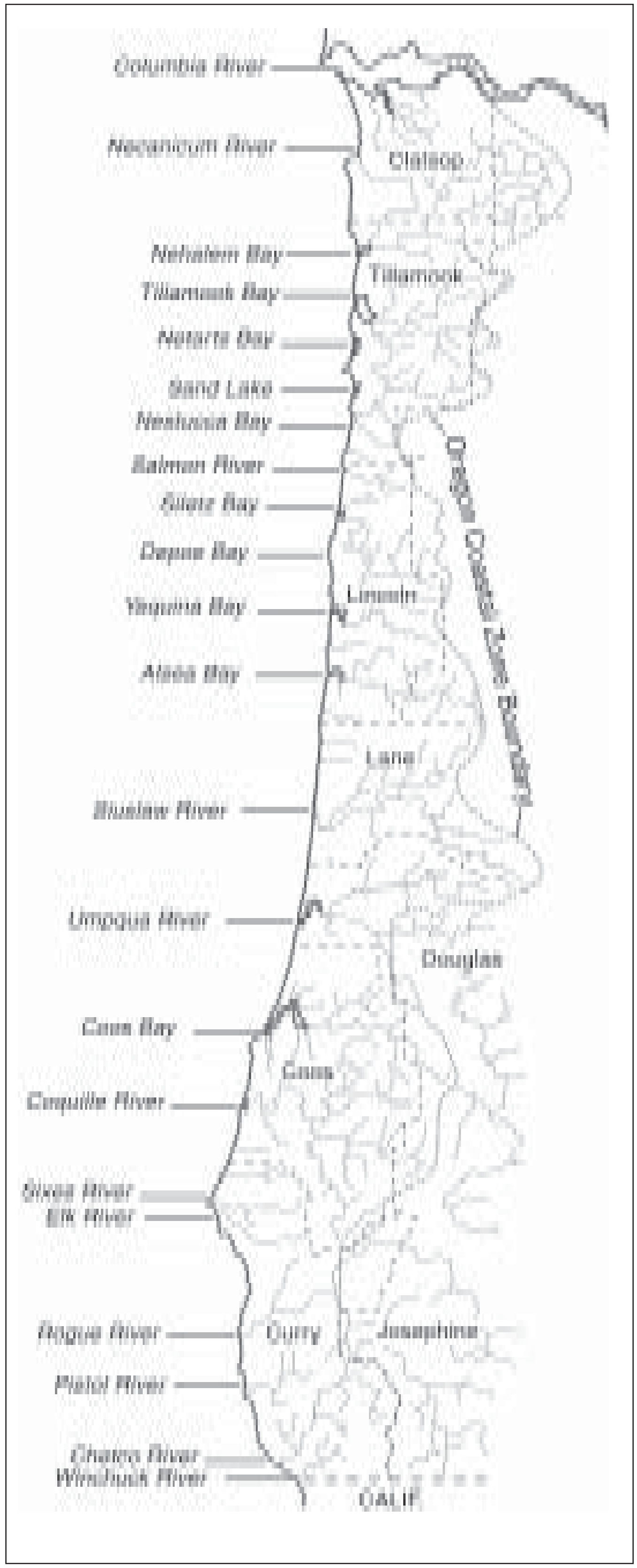


Figure 2.—*Oregon's principal estuaries.*

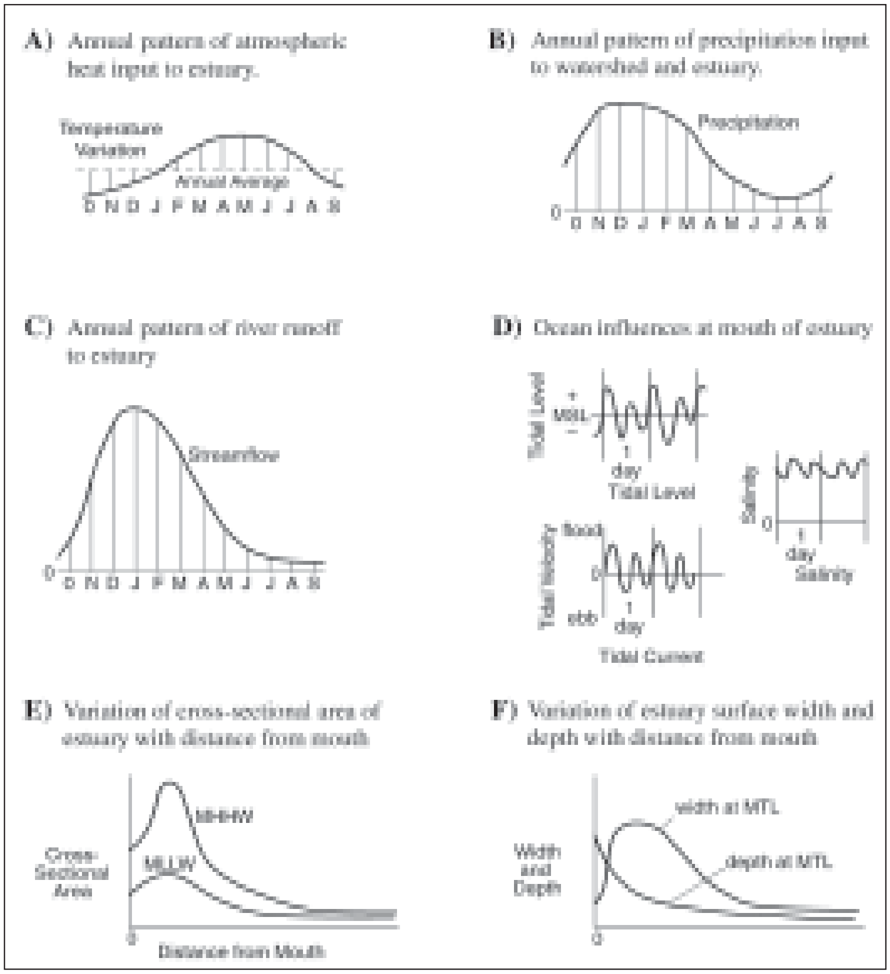


***Figure 3.**–Important physical factors affecting Oregon estuaries and their typical variability. (Modified from* General Planning Methodology for Oregon Estuarine Natural Resources, *Klingeman and Bella, 1973)*

Despite their small size, Oregon's estuaries play a vital role in the ecological and economic health of the coast and the entire state. For example, they are ecologically important to many fish and wildlife species, providing migration routes and habitat for reproduction, rearing, resting, and foraging.

Oregon's estuaries also serve coastal communities. Deep draft shipping, commercial fishing, port facilities, other businesses that depend on water access, and recreational uses are examples. Providing for these and other uses while protecting estuarine ecosystems and natural resources is the key challenge for public agencies, nongovernmental organizations, private businesses, and users.

Each of Oregon's estuaries is a unique ecosystem influenced by many variables–watershed size, geology, and land use; river gradient; the estuary's shape and size; and annual patterns of precipitation, river runoff, solar heat input, ocean tides, and fresh water–salt water mixing. Some of these variables can be generalized for Oregon's estuaries (Figure 3).

Typically, heat input increases during spring and summer, spurring biological productivity at the same time nutrient-rich water is upwelling along the coast. Except for the Columbia, local precipitation and streamflow are roughly *synchronous*. (As precipitation increases, so does streamflow.) Streamflow peaks on the Columbia are linked more closely to spring snowmelt in the Cascades and the Rockies.

Tides at the entrance to Oregon's estuaries are similar as well, but the ocean's influence within each estuary is unique. River flow and the shape of the estuary strongly affect mixing and circulation patterns, salinity zones, and the distribution of bottom sediments.

Oregon estuaries north to south

The *Columbia River estuary,* with more than 80,000 acres of surface area in Oregon alone, is larger than all of the other Oregon estuaries put together (Figure 2 and Table 1). Draining one of the largest river basins in North America (259,000 square miles), the Columbia's estuary is dominated by the river's freshwater inflow. Although the head of tide extends 146 miles upstream to Bonneville Dam, traces of salt water rarely are found above River Mile 30, even at low flow.

The freshwater nature of this estuary makes it very different from the smaller estuaries to the south. For example, of the more than 10,000 acres of Columbia estuary tidal marsh, only a small fraction are salt marsh. The rest are freshwater tidal wetlands.

From the Columbia River south to the Salmon River, the coastal mountains are a complex mix of sedimentary and volcanic rocks. Two estuaries—*Nehalem Bay* and *Tillamook Bay*—are relatively large by Oregon standards and have large watersheds. Other estuaries of the north coast—the *Necanicum River, Netarts Bay, Sand Lake, Nestucca Bay,* and *Salmon River*—are small and drain smaller watersheds. Netarts Bay and Sand Lake, with very small watersheds and limited freshwater input, essentially are saltwater lagoons.

South of the Salmon River are the *Siletz Bay, Depoe Bay, Yaquina Bay, Alsea Bay, Siuslaw River, Umpqua River, Coos Bay,* and *Coquille River* estuaries. The watersheds of these estuaries are moderate in size, except for tiny Depoe Bay and the much larger Umpqua system, which rises in the southern Oregon Cascades near Crater Lake and cuts through the Coast Range. These estuaries have large areas of salt marsh, eelgrass, and tidal flat habitat. The head of tide extends far upriver—41 miles on the Coquille, for example.

Along this part of the coast, the mountains are mostly older marine sediments and sands and clays eroded from ancient mountains to the south and east. These materials subsequently were folded and uplifted to form the Coast Range. Estuaries formed as sea level rose after the last ice age, drowning river valleys and stabilizing at roughly the present level about 6,000 years ago.

South of the Coquille River estuary at Bandon are six small estuaries—the *Sixes, Elk, Rogue, Pistol, Chetco,* and *Winchuck*. The estuaries of these steep-gradient rivers extend only a few miles upstream at most and have gravelly bottoms and little tideland (Table 1). These rivers drain out of the rugged Klamath Mountains and, except for the Rogue, have relatively small watersheds. During the summer, when flow becomes extremely low, the Sixes, Elk, Pistol, and Winchuck estuaries sometimes close off at the mouth as sand berms pile up and clog the entrance. The Rogue, like the Umpqua River to the north, drains a large watershed with headwaters high in the Cascades.

Table 1.–Geomorphic type, head of tide, habitat type and size, and watershed size for Oregon's estuaries.

Estuary	Geomorphic type	Head of tide (river mile)[1]	Intertidal area habitat type (acres)					Subtidal area (acres)	Estuary area (acres)	Watershed area (square miles)
			SM	**FM**	**FSS**	**TF**	**SAV**			
Columbia	RIV/DRM	146[3]	1,488	5,728	4,290	21,391	0	47,914	80,811	259,000
Necanicum	BB	~4	94	35	3	136	4	179	451	87
Nehalem	DRM	8.9	509	3	12	581	652	992	2,749	855
Tillamook	DRM	6	881	0	3	4,226	2,024	2,082	9,216	540
Netarts	BB	~5	228	0	0	1,224	957	334	2,743	14
Sand Lake	BB	~2	462	0	0	255	66	114	897	17
Nestucca	DRM	8.5	205	0	0	430	242	299	1,176	322
Salmon	BB	5	238	0	0	28	76	96	438	75
Siletz	DRM	22.6	274	0	0	425	461	301	1,461	373
Depoe[2]	DRM	<1	–	–	–	–	–	–	~25	15
Yaquina	DRM	21.8	619	2	0	807	968	1,953	4,349	253
Alsea	DRM	11.5	460	0	0	764	564	728	2,516	474
Siuslaw	DRM	22.8	746	0	0	541	338	1,435	3,060	773
Umpqua	RIV/DRM	29.2	1,054	52	95	1,196	399	3,748	6,544	4,560
Coos Bay	DRM	10.2	1,699	28	0	4,240	2,256	5,125	13,348	605
Coquille	DRM	~39	276	0	0	228	103	475	1,082	1,058
Sixes[2]	BL	~2	–	–	–	–	–	–	330	129
Elk[2]	BL	~1	–	–	–	–	–	–	290	94
Rogue	RIV/DRM	4.5	39	5	0	201	77	558	880	5,100
Pistol[2]	BL	~1	–	–	–	–	–	–	230	106
Chetco	DRM	3.4	0	4	0	9	103	55	171	359
Winchuck[2]	BL	~1	–	–	–	–	–	–	130	70
Total			**9,272**	**5,857**	**4,403**	**36,682**	**9,290**	**66,863**	**132,897**	**274,874**
% of total			7.0	4.5	3.3	27.8	7.1	50.3	100	

Source: *Oregon Estuary Plan Book,* 1987; DSL, 1989.

[1]The river mile (RM) on the major tributary stream where fluctuations in tidal elevations cease; for some estuaries, measurement begins at the mouth; for others, such as the Coos River, it begins where the river joins the estuary. (See DSL, 1989.)

[2]Specific habitat area data are not available for these smaller estuaries of the south coast.

[3]Although the head of tide on the Columbia River is RM 146, the "estuary," for habitat delineation purposes, extends only to RM 38, the upstream limit of the salt water mixing zone at the south end of Puget Island.

Key

Geomorphic type

DRM = drowned river mouth; RIV/DRM = river-dominated DRM; BB = bar-built; BL = blind/closed

Habitat type

SM = salt marsh; FM = fresh marsh; FSS = forested/scrub–shrub; TF = tidal flats; SAV = eelgrass/algae

Tides and tidal currents

What causes tides? What kind of tides do we experience along the Oregon coast? What happens when the tide enters a bay or estuary? The answers to these questions are critical to understanding how waters mix and circulate in estuaries, how and where different types of habitats develop, and how damaged or degraded estuaries might be restored.

Tides actually are very long period waves, with 12 hours and 25 minutes between successive crests (high tide) or troughs (low tide). See Figure 4. The wave length of the tide is equal to one-half the earth's circumference.

Many celestial bodies influence tides by their gravitational pull on the fluid ocean surface, but the moon and sun are by far the most important. Tides are strongest and the daily tidal range is great when the moon and sun align either on the same side of the earth (at the new moon) or on opposite sides of the earth (at the full moon). We call these *spring tides*. At the quarter moon, between new and full moons, tides are weaker, with smaller differences between the highs and lows. These we call *neap tides*. Over the course of a

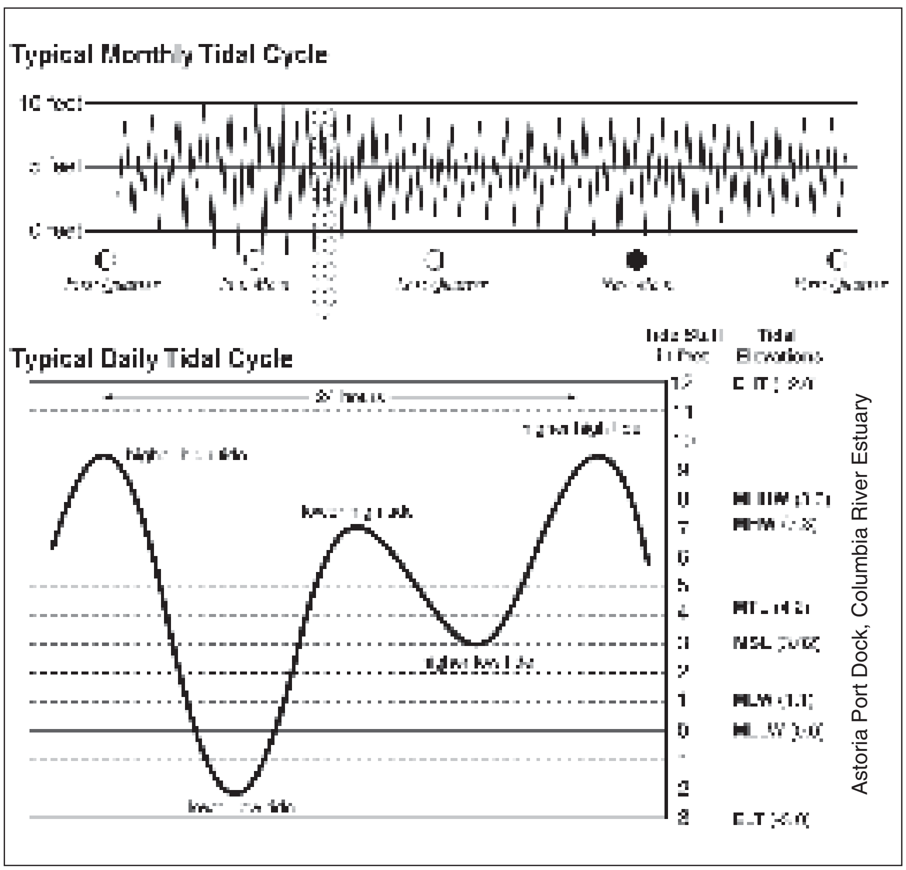


Figure 4.—*Tidal cycles, terminology, and typical elevations along the Oregon coast.*

Tidal Terminology

Extreme High Tide (EHT)—The highest projected tide that can occur. It is the sum of the highest predicted tide and the highest recorded storm surge.

Mean Higher High Water (MHHW)—The average height of the higher of the two daily high tides observed over a specific time interval.

Mean High Water (MHW)—The average of all observed high tides. The average is of both the higher high and the lower high tides recorded each day over a specific time period.

Mean Tide Level (MTL)—The average of the MHW and MLW at a given station.

Mean Sea Level (MSL)—A datum based upon observations taken over a number of years at various tide stations along the west coast of the United States and Canada.

Mean Low Water (MLW)—The average of all observed low tides. The average is of both the lower low and the higher low tides recorded each day over a specific time period.

Mean Lower Low Water (MLLW)—The average height of the lower of the two daily low tides observed over a specific time interval.

Extreme Low Tide (ELT)—The lowest estimated tide that can occur.

lunar month, there are two periods of spring tides (new and full moon) and two of neap tides (quarter moons). See Figure 4.

Each day along the Oregon coast, there are two high tides and two low tides of unequal height and duration (Figure 4). *Mixed semidiurnal tide* is the technical term for this kind of tide. The outgoing (receding) tide is called an *ebb tide*. The incoming (rising) tide is called the *flood tide*.

The *datum* or "zero mark" for measuring tidal elevations in our region is the mean lower low water (MLLW), which is the average of the lowest of the two daily low tides over many years.

The *mean tidal range* is the difference in elevation between the average of all low tides and the average of all high tides. It is a bit more than 6 feet along the Oregon coast. Extreme low tides may be 3 feet or more below MLLW, and extreme high tides can be 12 feet or more above MLLW—a difference of 15 feet! Figure 4 shows Oregon reference elevations for a number of important tidal elevations, all referenced to the zero datum (MLLW). Several of these elevations are particularly important for estuarine management and restoration.

Mean high water (MHW), the average of all observed high tides, sets the boundary between state-owned tideland and privately owned land. Most high salt marshes (generally between MHW and the upland) thus are privately owned, although they still are part of the estuary and subject to estuarine planning and regulation. This topic is discussed further under "Human uses and management of estuaries."

Tidal currents are horizontal movements of water associated with the rise and fall of the ocean surface. For drowned river mouth estuaries such as Nehalem Bay or Yaquina Bay, these currents generally are strongest on the ebb tide as river water that was backed up by the incoming tide moves out on the ebb. In bar-built estuaries with little freshwater inflow—Netarts Bay, for example—flood currents may be equally as strong as ebb currents. See "Physical classification of estuaries" below for descriptions of these different types of estuaries. The shape of an estuary, especially its channel constrictions, also affects current velocity.

The timing of the strongest currents varies by estuary, but generally they occur about midtide, when the "tide is running." Slack water—when there is no tidal current—generally occurs soon after low tide or high tide.

How the tide affects an estuary depends on four main factors:

- The range of the tide at the ocean entrance (difference in height between high and low tide)

- The shape of the estuary basin, which determines timing and elevations of the tide at any given location as it moves in or out of the estuary
- The size of the estuary's opening at its mouth, which determines how much water can enter and exit during the tidal cycle
- The amount and variability of freshwater inflow

All but the first of these factors are different for each Oregon estuary. Despite these differences, the tide's ecological roles generally are the same in all estuaries. As they ebb and flow, tides provide huge amounts of energy to estuaries. They mix and circulate dissolved plant nutrients and they redistribute organic detritus–the tiny bits and pieces of plants, bacteria, decomposing plankton, and other debris that small animals eat. Tides and tidal currents also strongly influence the development, structure, and function of estuarine habitats through their influence on temperature, inundation time, sunlight and heat exposure, and wind and wave energy.

Physical classification of estuaries

Although each estuary is unique, a number of classification systems have been developed to help sort out similarities and differences in form and function. Some of the most useful are explained below.

Geomorphology

Geomorphology relates to the origins and development of the landscape. From a geomorphic perspective, Oregon's estuaries are classified as drowned river mouth, bar-built, or blind (closed). See Table 1.

Drowned river mouth estuaries formed as ancient river valleys were flooded by the rising sea at the end of the last ice age. Today, these estuaries have relatively large coastal watersheds. They are freshwater (river) dominated during winter, when runoff is high, but saltwater dominated in the dry summer and fall. Coos Bay is a good example. The Columbia River estuary is a special kind of drowned river mouth estuary. It is river dominated and comparatively fresh all year long. The Umpqua and Rogue also are river dominated, but not to the same extent.

Bar-built estuaries such as Netarts Bay and Sand Lake are partially enclosed and sheltered by sand spits. They have very small watersheds and little freshwater input, and are strongly influenced by tides and seawater. Some estuaries, such as the Necanicum and Salmon, might be classified as either bar-built or drowned river mouth.

Blind or *closed estuaries* are open in the winter when rainfall and streamflow are high, but are closed at the mouth by sand bars during the summer when flows are low. The Sixes River estuary near Cape Blanco and other small south coast estuaries are examples.

Mixing and circulation

Characteristic patterns of salt- and freshwater mixing and circulation also are used to classify estuaries. Mixing and circulation types include stratified, partially mixed, and well mixed.

Stratified or "salt-wedge" conditions occur when both river flow and tides are strong. Seawater intrudes into the estuary along the bottom because it is slightly heavier than the freshwater coming downstream. At the boundary between the fresh- and saltwater layers, high shear forces allow only limited mixing between the two. In cross-section, the salt water looks like an intruding wedge along the bottom.

The Columbia River estuary is strongly stratified during strong tides in May and June, when annual river flow peaks. Stratified estuarine conditions also may exist during high winter flow and flood conditions in coastal estuaries such as the Nehalem or Siletz.

Well-mixed estuarine conditions occur when river flows are low and tides are weak. This situation occurs in many Oregon estuaries during summer and early fall before winter rains begin. Well-mixed, diluted seawater can be found far upstream in coastal rivers at these times.

Partially mixed conditions occur when both river flow and tides are moderate to high or strong. These conditions are typical during winter.

At different times of the year, any given estuary may fall into any of these classifications. Generally, however, estuaries that drain large river basins (the Columbia, Umpqua, and Rogue) more frequently exhibit stratified or partially mixed conditions than do estuaries with smaller drainages. These smaller estuaries typically are well mixed.

Mixing and circulation characteristics are important because they strongly influence an estuary's ecological functioning and thus the goods and services it provides. For example, mixing and circulation help determine where the best food resources are located and thus where predator and prey interact. Mixing and circulation patterns also determine how pollution concentrates or disperses and how long it takes to flush the system of wastes. Estuaries are tuned to these and other physical factors.

Salinity zones

Differences in salinity have a major influence on the biology of estuaries. Estuaries are divided into four distinct geomorphic salinity zones. The actual boundaries of these zones shift back and forth with tidal cycles and changes in river discharge.

The *marine-estuarine interface zone* is located immediately *outside* the mouth of an estuary. This zone is characterized by a mixture of seawater and freshwater in the range of 33 to 25 psu (practical salinity units). Where the volume of river discharge is high (the Columbia, Umpqua, and Rogue, for example), this zone can extend far out into the ocean. Where river discharge volume is relatively low (Yaquina Bay, for example), the marine-estuarine interface zone is confined to the area immediately offshore the river mouth and is strongly influenced by the ebb and flood of the tides.

The *marine-dominated lower estuary zone* is located just *inside* the mouth of the estuary and is characterized by high variability in salinity (30 to 18 psu). Bottom sediments in this zone are mainly fine sands of marine origin.

The *middle estuary mixing zone* is located farther up the estuary. Salinity in this zone ranges from 18 to 5 psu, and bottom sediments are a mixture of fine sands of marine origin, riverine sediments from the watershed, silt, and organic matter.

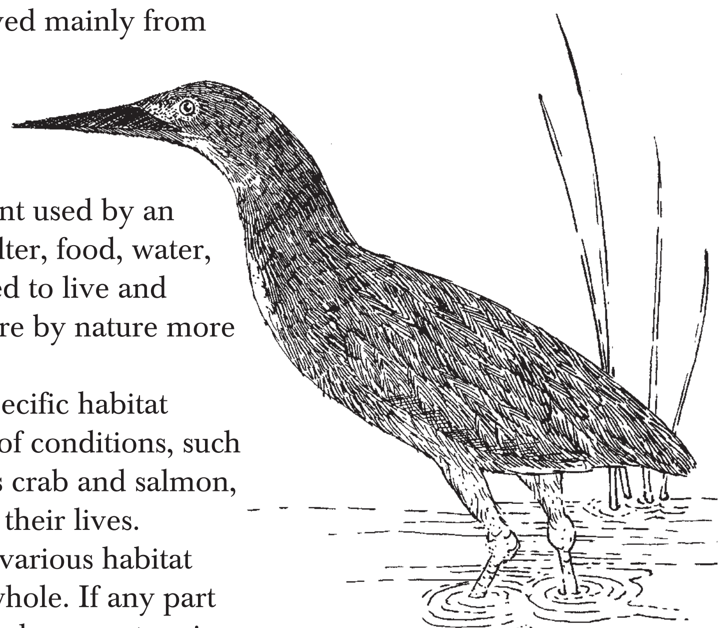
The *upper estuary riverine zone* extends from the mixing zone upriver to the head of tide. Salinity ranges from 5 to 0.5 psu—virtually fresh water at certain times of the year. Bottom sediments are fine sand, silt, clays, and other materials derived mainly from the watershed.

Estuarine habitats

Habitat is the portion of the natural environment used by an organism. It is where plants and animals find shelter, food, water, reproductive mates, and other resources they need to live and reproduce. Some habitats, such as salt marshes, are by nature more productive than others.

Some types of plants and animals have very specific habitat requirements, while others tolerate a wide range of conditions, such as those found in estuaries. Many species, such as crab and salmon, depend on different habitats at different stages of their lives.

Although we may "deconstruct" estuaries into various habitat types, they, like other ecosystems, function as a whole. If any part of an estuarine habitat is lost or degraded, the whole ecosystem is degraded.



Green heron

A number of classification systems have been developed to differentiate estuarine habitats. One example is the Cowardin classification system, which is used in the National Wetlands Inventory and is described in chapter II-9, "Wetlands." Many of these habitats and the organisms found in Pacific Northwest estuaries are illustrated in Figure 5 and described below.

Subtidal habitats

Subtidal estuarine habitats include *channel bottoms, slope bottoms,* and the *open water* above them. Plants and animals found in these habitats are influenced by the gradient of salinity, the availability of light, and the type of bottom sediments.

Bottom sediments range from coarse gravel and marine sands near an estuary's mouth to fine sands and silts of both marine and terrestrial origins farther up the estuary. Hard-bottom areas also are

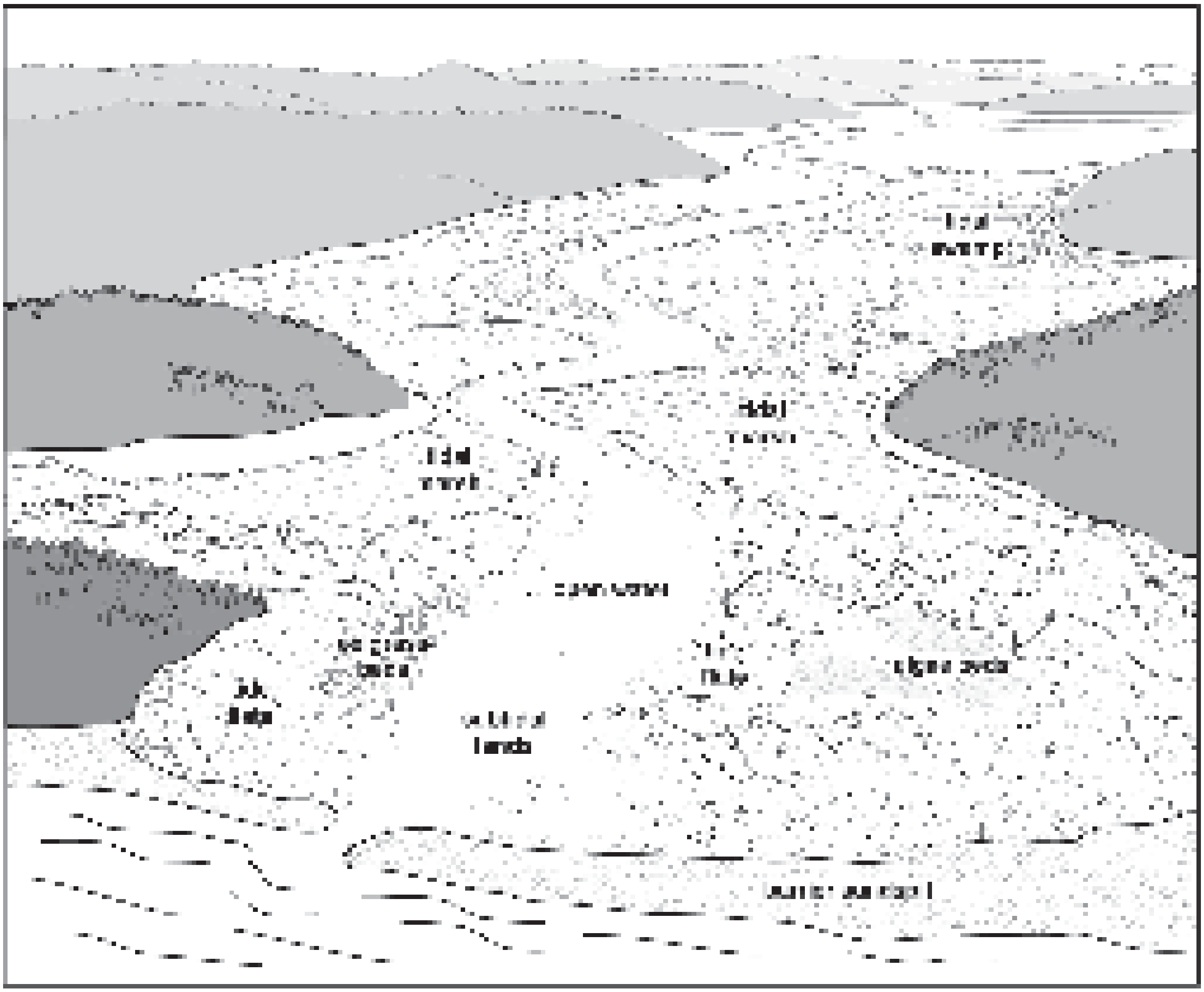


Figure 5.*–The different habitats in Oregon's estuaries support an abundance of plant and animal life. (Drawing modified from* Oregon Estuary Plan Book, *1987)*

common, most often near the ocean entrance or within deep channels. Ebb and flood tidal currents are strongest in channels. Here they mix fine sediments and organic detritus within the water column, scour hard-bottom areas, move sandy sediments along the bottom, and process and redistribute food resources up and down the estuary.

Channels are the migratory routes for upstream-bound salmon and other fish, while juvenile salmon frequent the shallows. Large clams that make their home in the sediments of slopes and deep channels may serve as seed stock for colonizers of the shallower tidal flats.

Water column productivity reaches its maximum in the channel, where salt- and freshwater mixing is greatest. This dynamic mixing zone, which moves upstream and downstream with the tide, is called the turbidity maximum. Predator and prey alike are attracted to this region, and here the physical, chemical, and biological transformations that make estuaries unique reach a crescendo.

Eelgrass beds are another key estuarine habitat found along shallow subtidal slopes where sunlight can penetrate. Eelgrass beds are discussed below under “Tidal flat habitats.”

Tidal flat habitats

Between the extreme low-water mark (about 3 feet below MLLW) and the mean tide level (about 4 to 5 feet above MLLW) are *tidal flats*. At low tide, tidal flats account for approximately one-third of Oregon’s estuarine surface area, more than twice the area of tidal marshes. Tidal flats dominate backwater sloughs, shallow marginal embayments, and low-tide islands in estuaries.

Tidal flat sediments vary, ranging from coarse sand toward an estuary’s mouth to fine sand, silt, and mud farther up the bay. The finer substrates often are referred to as soft-bottom habitats because they typically have a high water content and are stirred constantly by bottom-dwelling organisms.

Soft-bottom habitat can be recognized by anyone who has gone clamming in an Oregon estuary—perhaps it is where they left a boot behind. Bottom-dwelling organisms include a wide variety of clams, worms, shrimp, amphipods, and other animals that burrow below the surface. They feed on rich, detritus-laden tidal waters that they pump into their burrows, or on deposits of microscopic diatoms, bacteria, and organic detritus that form a slurry on the surface.

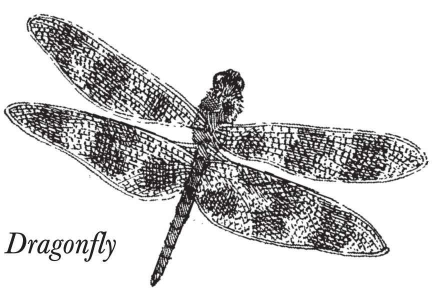
Tidal flats also are prime habitat for oysters and once supported vast numbers of the native oyster, *Ostrea lurida*. With the native oyster long ago harvested out, the imported Japanese oyster *(Crassostrea gigas)* is the predominant farmed species today.

Native *eelgrass beds (Zostera marina)* are found along the lower fringes of tidal flats and the shallow subtidal slopes they border. Like other rooted seagrass species, eelgrass' major life functions, including flowering and pollination, occur under water. Eelgrass beds serve a number of critical functions. They provide spawning substrate for herring; food for migrating black brant geese; and hiding places for young salmon, crab, and many other species. At low tide, blades of eelgrass lie across the exposed surface, protecting bottom-dwelling organisms from the hot summer sun. Eelgrass root systems also help stabilize the channels they border.

Highly productive *algae beds* also grow on tidal flats, particularly in the salty parts of an estuary. Sea lettuce *(Ulva),* filamentous algae *(Enteromorpha),* and mat-forming species *(Chaetomorpha)* are common. These species also help keep bottom-dwelling animals from drying out at low tide. Excessive algae growth, however, may be an indicator of too much nitrogen or other nutrients.

Tidal marsh and swamp habitats

At about the midtide level (4 to 5 feet above MLLW), there is a distinct transition from soft-bottom, algae, and eelgrass-dominated tidal flats to more upland-like environments dominated by rooted, flowering grasses, sedges, shrubs, and even trees. These are the estuary's tidal marsh and swamp habitats. The types of habitat and plant communities present are controlled mostly by elevation (which determines the tidal inundation period) and salinity. The tidal flooding of marshes and swamps in the upper reaches of an estuary is due in part to the "holdup" effect of the incoming tide on river flow. But even at low river flow, the tide may reach well upstream.



Dragonfly

Tidal marshes usually are highly dissected by complex networks of tidal creeks. These creeks serve as conduits for exchange of water, nutrients, and detritus, as well as low-tide refugia for small fish such as juvenile salmon. At high tide, these fish spread out across the marsh, feeding on estuarine invertebrates, aquatic insects, and even terrestrial insects wafting in from nearby riparian areas.

Tidal marshes in Oregon typically are composed of several distinct plant communities. In the lower and middle estuary, where bottom sediments are mostly fine sand, we find *low salt marsh*. Plant colonizers here include pickleweed *(Salicornia virginica)* and saltgrass *(Distichlis spicata)*. Where sediments are a bit more silty, colonizers include arrowgrass *(Triglochin maritimus),* threesquare bullrush *(Scirpus americanus),* and Lyngby's sedge *(Carex lyngbyei)*. The latter species forms large stands in low marshes, both salt and brackish.

At about 7 feet above MLLW (or approximately the MHW line), there often is a distinct break in elevation—sometimes 6 inches or more. This is where high salt marsh begins. This area is a highly diverse mix of grasses (e.g., tufted hairgrass, *Deschampsia caespitosa),* rushes *(Eleocharis* spp. and *Juncus* spp.), and other broadleaf species. It is flooded by tides only a few times each month, while lower marshes usually are flooded daily.

Where the high salt marsh transitions to upland, freshwater wetland species may dominate—skunk cabbage *(Lysichiton americanum)*, slough sedge *(Carex obnupta)*, silverweed *(Potentilla pacifica)*, willow *(Salix* spp.), and others. These areas are fed by freshwater seeps from hillsides or by small streams.

As estuarine waters become brackish and then fresh farther upstream, the flora and fauna of tidal marshes, flats, slopes, and channels gradually change. Some of the plant species in tidal freshwater marshes are the same as those in salt marshes, but freshwater wetland plants begin to dominate. These marshes, like the salt marshes farther downstream, may be highly dissected by tidal creeks. They are popular habitats for juvenile salmon (chinook, coho, and chum) and sea-run cutthroat trout beginning their acclimation to the marine environment.

Brackish and freshwater tidal swamps of Sitka spruce *(Picea sitchensis)* and redcedar *(Thuja plicata)* with understories of red alder *(Alnus rubra),* willows *(Salix* spp.), and emergent marsh species once were common along the Oregon coast, but now are rare. Most of these areas were logged, cleared, and diked for agricultural use in the late 19th century—more than 24,000 acres in the Columbia estuary alone.

Some of the best preserved remnant tidal swamps are on the Oregon side of the Columbia estuary, one where Big Creek empties into the estuary, and another just upriver at Blind Slough. Both are nature reserves.

Connections to the watershed

The condition and quality of a watershed's aquatic and upland ecosystems have an enormous influence on its estuarine habitats (Figure 6). Activities such as road construction; forestry; agriculture; and urban, suburban, and rural development all have an effect. The resulting runoff pollution and changes in the quantity and timing of water inflow are particularly important. Assessment and management of upland and riparian habitats are described in detail in Chapters II-4, "Upland Evaluation and Enhancement," II-5, "Terrestrial Riparian Area Functions and Management," and II-6, "Riparian Area Evaluation and Enhancement."

Figure 6.*—What happens in the watershed affects the estuary and near-shore coastal waters. (Photo: Jim Good)*

One of the most prominent links between estuaries and their watersheds relates to the life cycles of Pacific salmon and seagoing trout. The key role of estuaries in these species is discussed in the following section.

Salmon and estuaries

Recovery of salmon and steelhead stocks in the Pacific Northwest is a major environmental issue. The Oregon Plan for Salmon and Watersheds is a strategy for that recovery. Most recovery efforts have focused on improving freshwater stream and riparian habitat—primarily spawning and rearing areas.

However, by definition, any anadromous fish also must use an estuary for some part of its life. Pacific salmon and trout are no exception. Some travel quickly through the estuary to reach fresh water or salt water, while others linger longer, seeking food and shelter.

What functions do estuaries play in supporting salmonids, and how do historical and recent changes affect their capacity to fulfill these roles? Oregon's estuaries are particularly important for juvenile salmon for three reasons:

- Tidal creeks, marshes, eelgrass beds, and channels furnish young salmon with *productive feeding areas* where they forage and grow before heading out to sea (Figure 7).
- Shallow estuarine habitats *offer refuge from predators,* especially the marine mammals, birds, and fish that hunt for juvenile salmon in deep channels and near-shore areas.
- Brackish estuarine waters provide an *acclimation area for salmonid smolts* while they adapt to the marine environment.

Because estuaries are highly productive, salmon smolts often grow rapidly on the abundant food available there as they migrate to the ocean. The residence time and patterns for out-migrating juveniles differ substantially among and within species. Some move through to the ocean in just a few days, others forage in shallow embayments and backwater sloughs for months, and still others reverse their downstream migration and reenter freshwater streams for a time.

For a given species, research has shown that juvenile salmon with longer estuarine residence times have higher survival rates than those that move through quickly. Most likely this is because they grow larger and quicker before entering the sea and so are better able to avoid predators in the open ocean.

Five races of *chinook,* the largest but least abundant Pacific salmon, occur along the West Coast. Races are defined according to the season in which adults migrate from salt- to freshwater. Some populations enter coastal rivers and creeks in winter or spring, while others return in summer or fall. With the exception of a summer run in the Columbia, all chinook that use coastal Oregon streams are spring or fall migrants.

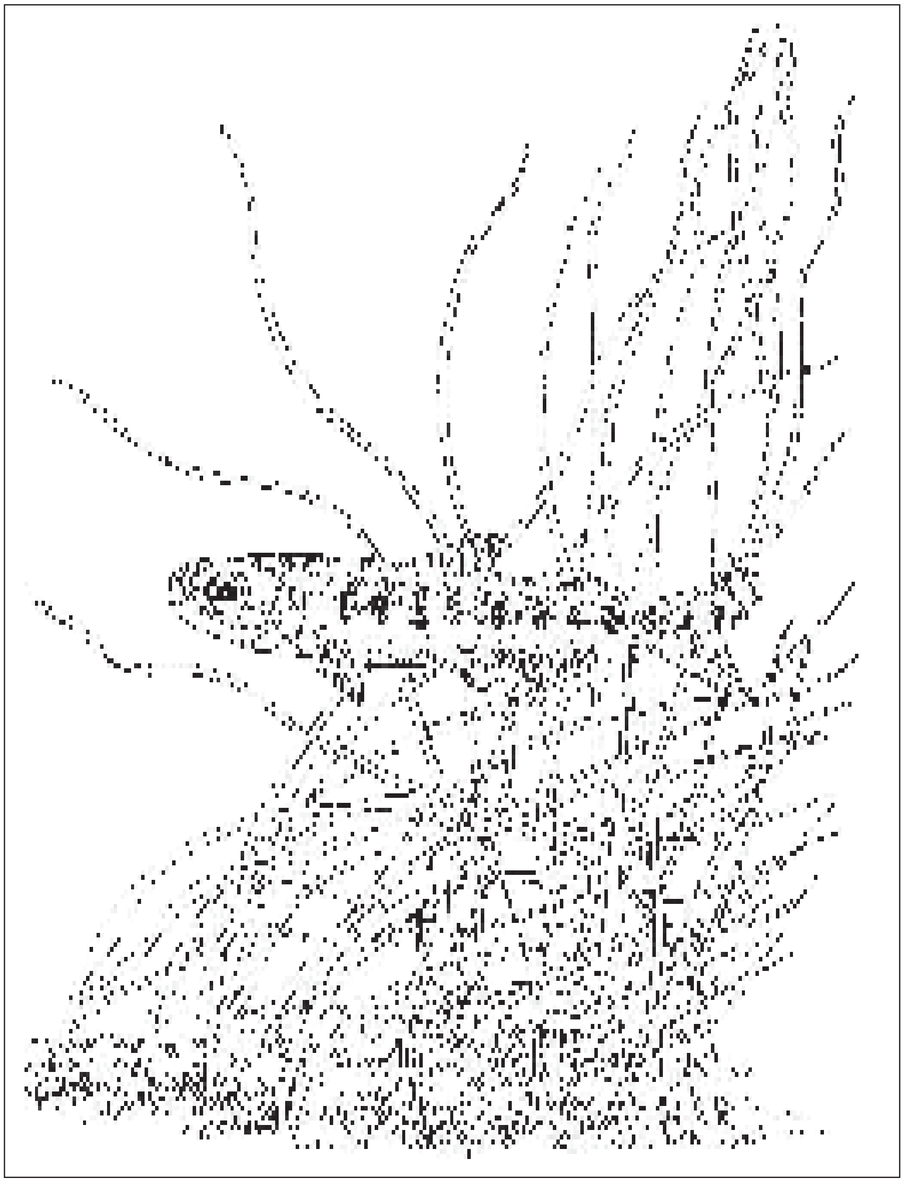


Figure 7.*—Eelgrass beds, tidal creeks, and marshes are good hiding and feeding areas for young salmon. (Drawing by Sharon Torvik, courtesy of South Slough National Estuarine Research Reserve)*

Chinook fry and smolts often descend rapidly from their natal streams to the ocean, but some individuals spend up to 18 months in fresh water. So-called *subyearling estuarine smolts* migrate to estuaries soon after hatching, where they feed and grow for several months before entering the ocean. *Subyearling riverine smolts* spend less than a year in freshwater and move quickly through the estuary on their way to the sea. *Yearling riverine smolts* remain a year in the river, migrating seaward through the estuary the spring after they hatch.

Like adults, juvenile chinook are carnivorous. They are opportunistic feeders, meaning they will eat whatever is available. In the estuary, they frequent an assortment of habitats, from mud flats to eelgrass beds, and consume a large variety of invertebrate and fish larvae, crustaceans, insects, and fish. One of their favored foods is an amphipod with a giveaway scientific name, *Corophium salmonis*.

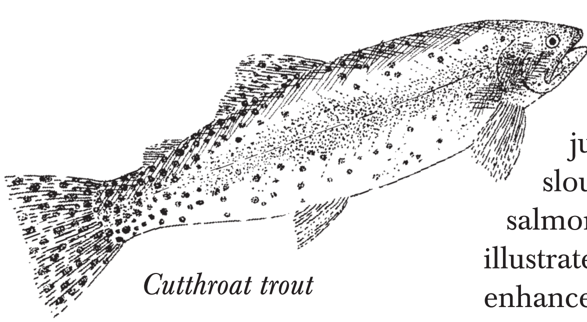
Coho salmon, which range along the Pacific coast from central California to northwestern Alaska, use all of Oregon's estuaries. Juvenile coho spend a year or more in fresh water before migrating to the ocean. Depending on location, smolts spend from a couple of days to a month or more in estuaries before heading to sea. Like chinook salmon, juvenile coho are opportunistic carnivores, feeding on large zooplankton and small crustaceans, insects, invertebrate and fish larvae, and juvenile fishes, including other salmonids.

Chum salmon occur from California to Alaska, but are most abundant in the northern part of their range. Soon after they absorb their yolk sacs, chum salmon fry head for the estuary, where they spend up to several months preparing for life at sea. Juvenile chum move throughout the estuary with tidal flows, frequenting tidal creeks, sloughs, and marshes. As opportunistic, carnivorous feeders, young chum salmon forage in shallow estuary waters for small crustaceans and terrestrial insects. Older chum move to deeper waters, where they prey on fish larvae, copepods, amphipods, and other crustaceans.

Steelhead spend little time in estuaries, usually just passing through on their way to the ocean (as smolts) or rivers (as adults). From February through May, *cutthroat* juveniles migrate from Oregon's coastal streams into estuaries, where they feed on insects, crustaceans, and fish. As they grow, young cutthroat show a marked preference for fish. Adult sea-run cutthroat often inhabit small tidal streams, sloughs, backwaters, and tidal freshwater regions of estuaries before fall rains spur their spawning migration. Some cutthroat reside permanently in estuaries.

It is not uncommon for adult salmonids occupying near-shore coastal waters to move into lower estuaries for brief periods to feed. Thus, estuaries serve as important feeding areas for both adult and juvenile salmonids. Additionally, just as some ocean-bound juvenile salmonids use the estuary to gradually acclimate to salt water, some returning adults use the estuary to reaccustom themselves to fresh water.

Historical changes to estuaries have greatly reduced the area and functions of estuarine habitats frequented by juvenile salmonids—mainly salt marshes, tidal creeks, and sloughs. Our understanding of the role that estuaries play in salmon life cycles is incomplete, but the evidence to date illustrates the high value of remaining habitat. Restoration and enhancement of estuarine habitats can increase production and



Cutthroat trout

acreage of salt marsh as well as the tidal creeks and eelgrass beds that provide food and shelter for salmonids. These actions will help restore estuaries' historical roles and provide a buffer against upstream disturbance and change.

Note: This section was adapted from *Salmon and Trout in Oregon Estuaries*, by Ken Oberrecht.

HUMAN USES AND MANAGEMENT OF ESTUARIES

People have been attracted to estuaries for millennia. In the Pacific Northwest, native peoples built their villages along the shore; harvested the abundant salmon, oysters, and other fish and shellfish; and used the estuaries as transportation and trading routes. Early Euro-American settlement of the coast centered around estuaries. Astoria, Newport, Reedsport, and Coos Bay (then Marshfield) were a few of these early cities.

Like native peoples, Euro-American settlers were attracted to estuaries by transportation convenience, vast natural resources, and flat land. Rivers were used to transport logs down to the estuary for storage, processing at local mills, or shipment to distant markets. The 20th century saw growth of existing and new settlements; improvements in ports and navigation; industrial and commercial development; and commercial and recreational exploitation of salmon, oysters, and other living resources. In recent decades, residential and recreational development has boomed along estuary shorelines, bringing demands for more public access and amenities. With all of this development has come a plethora of unwanted by-products—pollution, conversion of valuable wetlands to other uses, decline of native fisheries, invasion of estuaries by nonnative nuisance species, and crowding of highways and recreational facilities.

These historical and more recent changes are discussed later in this chapter.

Who owns Oregon's estuaries?

The State of Oregon, as trustee for its citizens, owns and manages most of the land beneath tidal and commercially navigable waters, up to mean or ordinary high water (Figure 8). When Oregon was admitted to the Union in 1859, it received title to these submerged and submersible lands from the Federal government, as other states did before and have since.

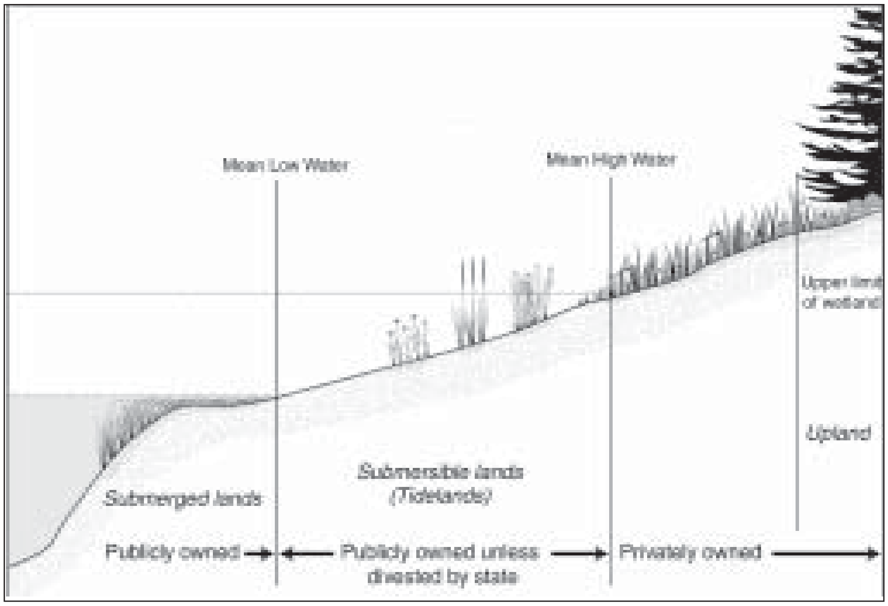


Figure 8.*—Ownership boundaries for Oregon estuaries.*

Through the State Land Board, Oregon has sold or leased some of these lands and still can do so. For example, tracts of tideland in larger estuaries such as Coos Bay, Tillamook Bay, Yaquina Bay, and the Umpqua estuary were sold before and just after the turn of the 20th century, often for oyster farming.

However, the state may not relinquish its responsibility to protect certain public rights to these lands. Collectively termed the "Public Trust Doctrine," these rights permit the public to navigate on and over the water; to harvest fish, shellfish, and waterfowl; and to use the water as a highway of commerce. Court decisions in the 1980s expanded public trust rights to include recreational and aesthetic values as well.

Protection of these rights is a fundamental principle used by the State of Oregon in leasing and regulating uses of state waterways and wetlands, including estuaries. Through the state removal-fill law (discussed later in this chapter and in Chapter II-9, "Wetlands"), the public trust concept has been extended to all waters of the state, both public and private, including wetlands. Even the areas of submerged land in estuaries that were sold to private parties nearly a century ago are subject to the public trust doctrine. Only permanent filling–rare today–cancels these public rights.

Although the state owns tidelands up to MHW, the extensive high tidal marshes that fringe estuaries are mostly in private ownership (Figure 8). This situation makes it necessary to involve many landowners when considering restoration and enhancement activities.

Estuary changes–prehistory, early white settlement, and development to 1970

Oregon's estuaries are affected by both natural and human disturbances. Probably the most catastrophic natural disturbances to estuaries are the large earthquakes and tsunamis that occur every 300–600 years along the Cascadia subduction zone just offshore. When one of these great earthquakes strikes (the last event occurred in 1700), coastal lands subside, soils liquefy, landslides are triggered, and tsunami waves inundate the coast and estuaries. No doubt these events have resulted in major environmental changes in estuaries. Major forest fires that predate Euro-American settlement of the region are another example of natural disturbances that likely had significant estuary impacts due to the large pulses of wood, debris, and sediment that followed. Climate variability associated with El Niños, La Niñas, and longer period oscillations likely affect estuarine ecology in more subtle ways, but these have not been studied.

Native peoples used estuaries and tidal wetlands for hunting, fishing, and shoreline settlement for several millennia, but their use likely had little adverse effect on the health and functioning of these ecosystems. Euro-American settlement of the region began in earnest in the mid-19th century. Over the next 150 years, physical alterations designed to improve navigation and provide land for growing ports, cities, and small farms changed the estuarine landscape but degraded its natural functions.

Most apparent are the direct physical changes. Examples include:

- Stabilization of river mouths with jetties–10 estuaries
- Dredging to deepen or stabilize river channels and construct turning basins and marinas–nine estuaries
- Stabilization of shorelines with rock or bulkheads–all estuaries
- Diking and draining of tidal marshes for agriculture–15 estuaries, more than 41,000 acres (Figure 9)
- Filling for industry, ports, marinas, highways, and similar development–all estuaries, nearly 8,000 acres (Figure 9)

These physical changes reduced the overall size of Oregon's estuaries by about one-quarter by 1970 (Table 2 and Figure 10). In most estuaries, the greatest change was the diking or filling of tidal swamps, marshes, and shallow

***Figure 9.**–This former tidal wetland in Warrenton, Oregon, illustrates typical physical alterations in Pacific Northwest estuaries–diking, draining, farming, logging, filling for railroad and highway construction, airport construction, and commercial and residential development. (Photo: Jim Good)*

flats. By 1970, tidal marshes and swamps along the Oregon coast had been reduced by two-thirds (Table 2 and Figure 10). Two estuaries–the Nestucca and Coquille–lost more than 90 percent of their tidal wetlands. Tillamook Bay lost 79 percent, and the Nehalem 75 percent. In absolute terms, the Columbia estuary lost the most tidal marsh and swamp habitat (Figure 11), followed by the Coquille, Tillamook, Nestucca, Coos, Nehalem, Yaquina,

Table 2.–Change in total area and area of vegetated wetlands (tidal marshes and swamps) for Oregon's 17 largest estuaries, due to filling and diking that occurred from about 1870 to 1970.

Estuary	Actual 1970 area (acres)[1]		Veg. wet. filled[2]	Veg. wet. diked[3]	Estimated 1870 area (acres)[4]		Percent change (1870–1970)	
	Veg. wet.	Total			Veg. wet.	Total	Veg. wet.	Total
Columbia	16,150	119,220	5,660	24,390	46,200	156,190	-65%	-24%
Necanicum	132	451	15	–	147	466	-10%	-3%
Nehalem	524	2,749	27	1,544	2,095	4,320	-75%	-36%
Tillamook	884	9,216	355	2,919	4,158	12,490	-79%	-26%
Netarts	228	2,743	5	11	244	2,759	-7%	-1%
Sand Lake	462	897	4	5	471	906	-2%	-1%
Nestucca	205	1,176	1	2,159	2,365	3,336	-91%	-65%
Salmon	238	438	12	301	551	751	-57%	-42%
Siletz	274	1,461	2	399	675	1,862	-59%	-22%
Yaquina	621	4,349	253	1,240	2,114	5,842	-71%	-26%
Alsea	460	2,516	25	640	1,125	3,181	-59%	-21%
Siuslaw	746	3,060	41	1,215	2,002	4,316	-63%	-29%
Umpqua	1,201	6,544	106	1,112	2,419	7,762	-50%	-16%
Coos Bay	1,727	3,348	1,260	2,100	5,087	16,708	-66%	-20%
Coquille	276	1,082	55	4,545	4,876	5,682	-94%	-81%
Rogue	44	880	27	3	74	910	-41%	-3%
Chetco	4	171	5	0	9	176	-56%	-3%
Total	24,176	170,301	7,853	42,583	74,612	227,657	-68%	-25%

[1]Data for 1970 estimates are from the *Oregon Estuary Plan Book* (Cortright and others, 1987), except for the Columbia, where estimates are based on Thomas, 1983.
[2]Data on filled lands are from filled state lands inventories (Oregon Division of State Lands, 1972). For this table, since the bulk of filled lands are adjacent to the shore, it was assumed that they were vegetated tidal wetlands. This may have resulted in a small error in totals and percent change.
[3]Data on diked lands are from Thomas, 1983 for the Columbia estuary; from S. Rumrill for Coos Bay (personal communication, 1999); and from unpublished, preliminary analyses of National Wetland Inventory maps, soil surveys, and aerial photos for the remaining estuaries (C. Cziesla, S. O'Keefe, A. Gupta, and J. Good, 1999).
[4]1870 area estimates were derived by adding the area of filled land and diked land to the 1970 area estimates.

Siuslaw, and Umpqua estuaries (Table 2).

Despite these huge changes in Oregon's estuaries, large areas of intact tidal marsh, flats, and other productive, healthy habitat remain today or are being restored in most estuaries. But none of Oregon's estuaries can be restored to the relatively pristine conditions of 150 years ago. At the very least, watershed dams, logging, agriculture, and rural settlement have changed the volume and timing of water inflow and inputs of sediment and other runoff pollution.

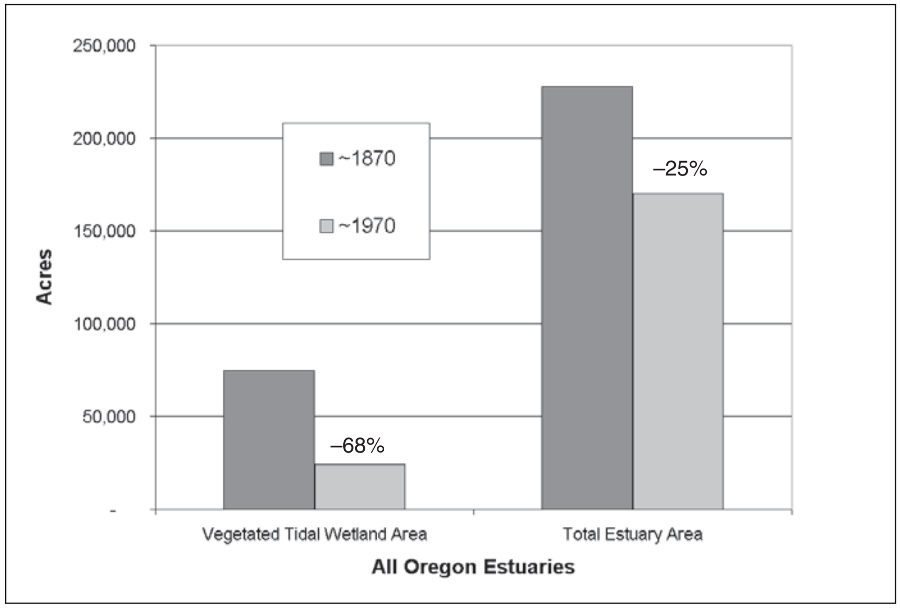


Figure 10.*—Change in total area and area of vegetated wetlands (tidal marshes and swamps) for Oregon's 17 largest estuaries, due to filling and diking that occurred from about 1870 to 1970. (Data from Table 2)*

Other less visible changes also have occurred, including some that have greatly influenced the ecological character and functions of our estuaries. Examples include:

- Massive harvesting and decline of native salmon and oysters
- Purposeful introduction of species such as striped bass, shad, the soft-shell clam, and the Japanese oyster
- Accidental introduction of dozens of species from other parts of the world, many through the discharge of ballast water by ships from foreign ports
- Changes in the timing of freshwater inflow and sedimentation due to watershed logging, road construction, and log transport down rivers
- Changes in the quantity of available fresh water associated with the damming of rivers for power production and municipal and industrial water supply

Estuary changes and threats– 1970 to present

In the late 1960s, coastal residents declared a "crisis in Oregon's estuaries." Two major reasons for concern were unregulated dredging for water access to land and filling of tidal marshes and flats to create new shoreland for development.

Governor Tom McCall responded by placing a moratorium on dredging and filling of Oregon's bays. In 1971, the state legislature

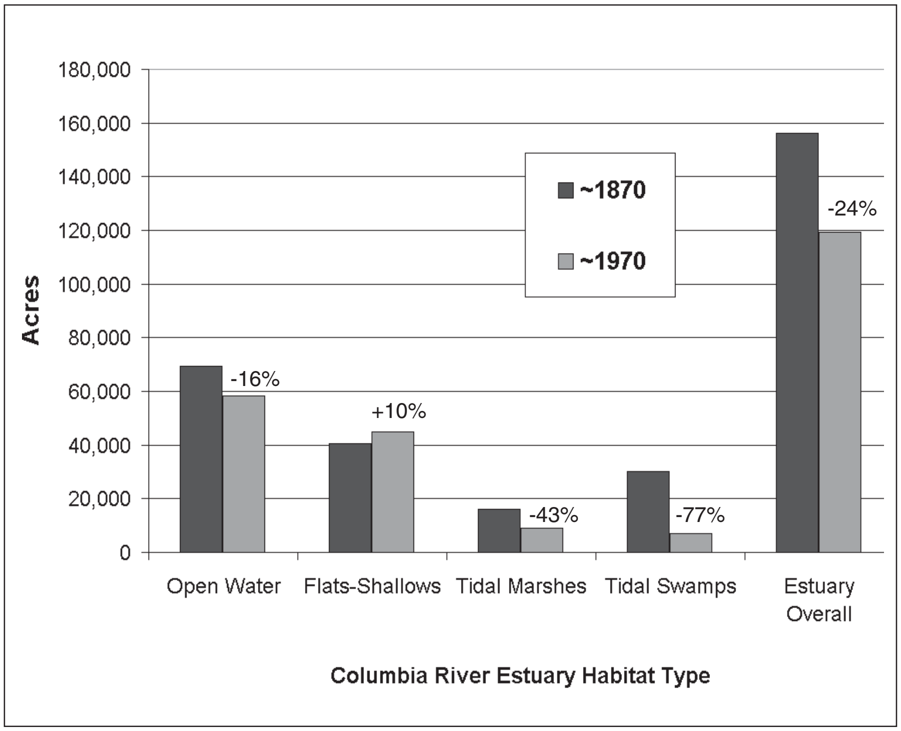


***Figure 11.**—Change in Columbia River estuary habitats from about 1870 to 1970. (Data from* Changes in Columbia River Estuary Habitat Types Over the Past Century, *Thomas, 1983)*

passed a law to regulate these activities in estuaries and other waterways. These actions spurred long-range planning for protection and development of estuaries. Local governments and state agencies joined together to develop plans for Yaquina, Coos, and Tillamook bays. These plans served as prototypes for the estuary planning efforts that eventually became a central feature of Oregon's coastal management program. These early efforts at identifying protection and development priorities were among the first of their kind in the nation and contributed to Oregon's well-deserved reputation as an early leader in environmental management.

Estuary plans—balancing protection and development

All of Oregon's estuaries have comprehensive land- and water-use management plans that guide where and how development and other uses may occur. The plans are part of local comprehensive plans that were developed through intensive collaborative planning efforts in the late 1970s and early 1980s. They were guided by Statewide Planning Goals 16 (Estuarine Resources) and 17 (Coastal Shorelands), adopted in 1976 by the Land Conservation and Development Commission. They are implemented through local development ordinances and through state and federal regulation of filling, dredging, in-water construction, and other activities.

Oregon's estuary plans and the rules that guide their development and implementation are described in the *Oregon Estuary Plan Book,* published in 1987 by the Department of Land Conservation and Development's coastal management division (see "Resources"). Highlights of the plans are summarized below.

- *Overall estuary classification*–Goal 16 (Estuarine Resources) requires that each estuary be classified according to the

Table 3.–Overall classification and management unit or zoning acreage for Oregon's estuaries.

Estuary	Overall estuary classification	Subtidal zoning				Intertidal zoning				Estuary summary
		NAT	CON	DEV	Subtotal	NAT	CON	DEV	Subtotal	
Columbia	Deep draft	970	44,051	2,894	47,915	15,588	17,233	77	32,898	80,813
Necanicum	Conservation	0	179	0	179	271	252	0	523	702
Nehalem	Shallow draft	18	837	145	1,000	1,592	114	41	1,747	2,747
Tillamook	Shallow draft	103	1,942	78	2,123	4,659	2,378	55	7,092	9,215
Netarts	Conservation	160	178	0	338	2,232	174	0	2,406	2,744
Sand Lake	Natural	140	0	0	140	758	0	0	758	898
Nestucca	Conservation	50	261	0	311	771	93	0	864	1,175
Salmon	Natural	98	0	0	98	340	0	0	340	438
Siletz	Conservation	33	294	0	327	1,077	58	0	1,135	1,462
Depoe Bay [1]	Shallow draft	–	–	–	–	–	–	–	–	–
Yaquina	Deep draft	2,037	1,301	1,011	4,349	1,838	402	106	2,346	6,695
Alsea	Conservation	162	572	0	734	1,681	100	0	1,781	2,515
Siuslaw	Shallow draft	100	1,257	84	1,441	1,385	209	25	1,619	3,060
Umpqua	Shallow draft	1,947	817	984	3,748	2,393	240	161	2,794	6,542
Coos	Deep draft	1,580	2,493	2,556	6,629	6,671	679	572	7,922	14,551
Coquille	Shallow draft	4	368	103	475	529	65	12	606	1,081
Sixes[1]	Natural	–	–	–	–	–	–	–	–	–
Elk[1]	Natural	–	–	–	–	–	–	–	–	–
Pistol [1]	Natural	–	–	–	–	–	–	–	–	–
Rogue	Shallow draft	19	461	95	575	97	182	27	306	881
Chetco	Shallow draft	4	94	55	153	1	17	1	19	172
Winchuck [1]	Conservation	–	–	–	–	–	–	–	–	–
Total		**7,425**	**55,105**	**8,005**	**70,535**	**41,883**	**22,196**	**1,077**	**65,156**	**135,691**

Source: *Oregon Estuary Plan Book,* 1987.

[1]No zoning acreage data are available for these smaller estuaries.

Zoning categories

NAT = Natural management unit (high protection)

CON = Conservation management unit (moderate protection)

DEV = Development management unit (reserved for water-dependent uses)

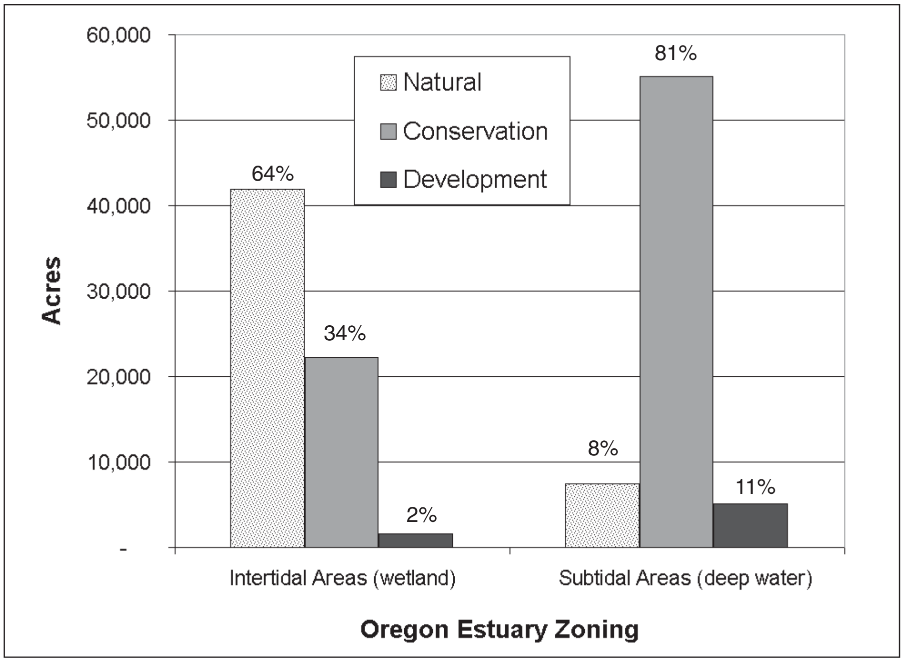


Figure 12.*—Combined intertidal and subtidal habitat zoning acreage for 22 Oregon estuaries. (Data from the* Oregon Estuary Plan Book, *1987)*

highest level or intensity of development permitted there. There are five natural estuaries, six conservation estuaries, eight shallow draft development estuaries, and three deep draft development estuaries (Table 3, column two).

- *Individual estuary zoning*–Within each estuary, using the overall classification and specific Goal 16 criteria, estuarine habitats are designated as natural, conservation, or development "management units" or zones (Table 3). Within each type of zone, uses either are permitted outright, conditionally permitted, or not permitted, depending on the management objective for that category. Coastwide, the tidal marshes, flats, and other estuarine wetlands that have not been altered by filling or diking are well protected from future alterations; 64 percent are in Natural management units and 34 percent in Conservation units (Table 3 and Figure 12).
- *Adjacent shoreland zoning*–Shoreland development is planned to be consistent with estuary zoning. For example, estuary Development zones generally abut water-dependent shoreland zones. Nearly 100 shoreland sites totaling more than 3,500 acres have been reserved for water-dependent development.

Regulating dredge and fill in estuaries—how effective is it?

Dredging, filling, in-water construction, and other uses are regulated in Oregon's estuarine wetlands and deep-water habitats much as they are in other wetlands and waterways through the Removal-Fill Law. (See Chapter II-9, "Wetlands.") However, the criteria for issuing permits in estuaries are stricter:

- Proposed uses must be water-dependent.
- A public need must be served.
- There must be no alternative upland site that could accomplish the same purpose.
- Unavoidable impacts must be minimized and compensated for by habitat mitigation.

Furthermore, the Division of State Lands and the U.S. Army Corps of Engineers may not issue permits in areas protected by local estuary plans.

How well have the Removal-Fill Law and estuary plans worked to limit direct physical alterations? Between 1971 and 1987, based on Division of State Lands records compiled by Fishman Environmental Services, just 19 acres of estuarine intertidal habitat were filled (0.03 percent of the 1970 base). About 5 acres of habitat were restored or created to compensate for part of that loss. Since protective zoning was established in the early 1980s, fill losses have been minimal.

Dredging between 1971 and 1987 involved about 111 acres of estuary area, mostly subtidal areas for navigation channel maintenance. As with filling, dredging has declined markedly since the early 1980s. Data have not been compiled since 1987, but estimates of additional filled and dredged areas are quite small.

Acquisition for preservation and conservation

Acquisition by purchase or easement for preservation and conservation purposes is one of the best ways to protect estuarine areas, particularly privately held high marshes and swamps above the state ownership line. (Note in Figure 8 that state tideland extends only up to MHW.) More than 10,000 acres of tidal brackish and freshwater wetlands in the Columbia River estuary are managed for wildlife by the U.S. Fish and Wildlife Service. Three additional refuges with significant salt marsh and tidal flats are located in the Nestucca, Siletz, and Coquille estuaries, and there are plans to include more land under conservation protection.

The South Slough National Estuarine Research Reserve in Coos Bay is another area managed for conservation. Research and education are its primary missions. South Slough Reserve includes 220 acres of salt marsh, 180 acres of tidal fresh marsh, 550 acres of tidal flats, 160 acres of subtidal submerged aquatic vegetation, 200 acres of open-water channels, and 3,460 acres of upland forests–4,770 acres in total.

Private conservation groups such as The Trust for Public Lands, The Nature Conservancy, and local land trusts also hold some estuarine wetlands for conservation management.

Pollution and pollution control

Located as they are at the “bottom” of watersheds, estuaries collect a variety of pollutants–introduced nutrients and organic matter, toxic metals, pesticides, herbicides, pathogenic bacteria and viruses, oil and other hydrocarbons, sediment, radioactive waste, plastic debris, and other trash.

Pipeline discharges–known as *point sources*–are responsible for some of these pollutants. Typical point sources in our region include municipal sewage treatment plants, power generation facilities, seafood processing plants, and pulp and paper mills.

Less obvious and more difficult to detect and control are pollutants from dispersed land runoff–*nonpoint sources*. Eroded soil, fertilizers, pesticides, and herbicides that run off from cropland, pastures, and forest land are major sources of pollution (Figure 13). So are septic tank wastes that drain or leach into coastal waters. Urban runoff is another example. Stormwater laden with oil, grease, fertilizer, pesticides, herbicides, and toxic metals washes into streams and rivers, and eventually into estuaries and near-shore waters.

Other pollution threats to estuaries include rare but potentially devastating oil spills, such as the 1999 *New Carissa* spill near Coos Bay.

Nonnative aquatic nuisance species, discussed later in this chapter, represent a growing and significant form of biological pollution that enters estuaries through point and nonpoint sources. Biological pollutants present a special cleanup challenge because, once released, they reproduce and spread on their own.

Estuaries and coastal waters can assimilate certain kinds and levels of pollutants, but their capacity sometimes is overwhelmed, stressing ecosystems and the organisms that live there. In an effort to limit pollution, the U.S. Congress and the Oregon legislature have passed laws to regulate point source discharges, manage runoff pollution, and help prevent and respond to spills of oil and other hazardous waste. Literally billions of dollars have been spent to upgrade municipal sewage treatment facilities throughout the U.S. in the past 3 decades, and billions of dollars more have been invested by private business to reduce and treat industrial wastes.

Figure 13.–*Runoff from agricultural land transports animal wastes, soil, fertilizers, herbicides, and pesticides into streams, rivers, and eventually estuaries.*

What laws and agencies are designed to limit water pollution? Government uses a combination of “carrot and stick” approaches. At the federal level, the principal law for controlling point and nonpoint sources of pollution is the *Clean Water Act* (CWA, formerly the Federal Water Pollution Control Act). The U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (Corps) have key responsibilities for implementing the CWA.

Many key provisions of the CWA, however, are delegated to state water-quality agencies–in Oregon, the Department of Environmental Quality (DEQ). DEQ administers the CWA Section 402 *National Pollutant Discharge Elimination System*–the permit program for regulating pipeline discharges. DEQ also is responsible for nonpoint source pollution control programs (e.g., CWA Section 319), as well as for certifying that Corps-issued permits for wetland or waterway alterations meet state and federal water-quality standards (CWA Section 401).

Another important coastal pollution control law is the *Ocean Dumping Act* (ODA). The Corps administers the ODA's Section 103 permit program, which regulates the transportation and dumping of wastes into coastal or offshore waters. Industrial waste dumping no longer is permitted in U.S. waters, so ODA permits today are mainly for disposal of clean sand dredged from coastal navigation projects. EPA must approve offshore dumping sites.

Another provision of the CWA set up the *National Estuary Program* in 1987. Two National Estuary Projects (NEPs) have been established in Oregon–the Tillamook Bay and Lower Columbia River estuary projects. For both estuaries, Coordinated Conservation and Management Plans (CCMPs) were completed in 1999 and are being implemented through local, state, federal, and private-sector partnerships.

Despite years of planning and voluntary programs, nonpoint source pollution problems have persisted or worsened over the past several decades. Congress responded in 1990 with Section 6217 of the Coastal Zone Act Reauthorization Amendments. The 6217 program attempts to link *enforceable* state coastal zone management policies with *voluntary* nonpoint source pollution control efforts promoted by state water-quality agencies.

In theory, this program makes good sense because poor land management is a major cause of nonpoint source pollution, and pollution reduction programs require changed land-use and management practices. For example, restoration and enhancement projects can create streamside filter strips to intercept runoff pollution that otherwise would go directly into streams and estuaries. The Section 6217 program has yet to achieve its objectives, however, in part because it is an ambitious, long-term undertaking and in part because funding has been sparse.

Oil spill prevention, contingency planning, response, and recovery are addressed under the national and state *Oil Pollution*

Acts. The most recent versions were passed in the wake of the disastrous 1989 *Exxon Valdez* oil spill in Alaska. Under these laws, the U.S. Coast Guard, the Oregon DEQ, and the ship's agent all have major responsibilities for response and recovery, with the ship's owner assuming principal financial responsibility. In Oregon, the 1999 grounding of the *New Carissa* and the subsequent oil spill, Natural Resource Damage Assessment, and cleanup operation serve as an excellent local case study of this process (Figure 14).

State and federal settlements for oil spill environmental damages have funded a number of estuarine restoration projects in the Pacific Northwest.

Nonnative species introductions

Some nonnative species introduced to Oregon estuaries generally are not considered problems. Examples include the eastern soft-shell clam *(Mya arenaria),* striped bass *(Roccus saxatilis),* American shad *(Alosa sapidissima),* and Japanese oyster *(Crassostrea gigas)*. These species, in fact, are highly valued for their contributions to recreational and commercial fisheries and provide economic incentives for keeping estuarine waters clean.

Other introduced species are not so welcome in the Pacific Northwest. The European green crab *(Carcinus maenus),* Chinese mitten crab *(Eriocheir sinensis),* saltmarsh cordgrass *(Spartina alterniflora),* and purple varnish clam *(Nuttallia obscurata)* are examples. They have the potential to disrupt ecosystem processes, out-compete valued species, or change habitat structure. These species are known as *aquatic nuisance species* (ANS).

Dozens, perhaps hundreds, of less prominent plant and animal species have invaded Oregon's estuaries, including microscopic and disease-causing organisms. Not all are nuisances, but they certainly have changed and will continue to change estuaries, sometimes for the worse.

Note that the difference between "nonnative" species

Figure 14.*—The* New Carissa *oil spill was a reminder that estuaries are extremely vulnerable to unpredictable pollution events. (Photo: NOAA)*

and “nuisance” species basically is a value judgment. The two definitions are gray and shifting, depending on the interests at stake. Even some native species are considered a “nuisance” by some people. Examples are burrowing mud shrimp and ghost shrimp in oyster-growing areas such as Tillamook Bay, and harbor seals that feed on returning adult salmon at the mouths of estuaries.

The European green crab, long established on the East Coast, was first seen in San Francisco Bay in 1989 and apparently has migrated north to Humboldt Bay, Coos Bay, and other Oregon estuaries (Figure 15). Biologists and the fishing industry are concerned that this voracious, predatory, and highly adaptable species will affect native and commercial shellfish populations.

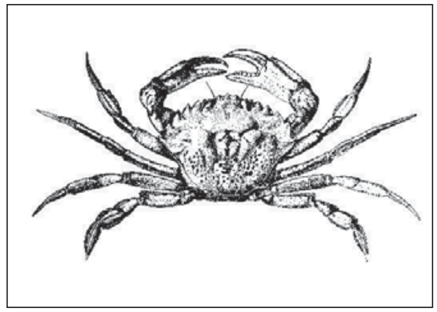


***Figure 15.**—Alien invader: the European green crab has been found in many Oregon estuaries and may compete with native species.*

The Chinese mitten crab is another threat to Northwest estuaries and upstream freshwater systems. It has become well established in San Francisco Bay, spreading as far as 200 miles up into the delta region. This species may have been introduced illegally for harvest or accidentally via shipping. The mitten crab is *catadromous*, i.e., it spends its adult life in fresh water and returns to the estuary to reproduce.

This species spreads and multiplies rapidly, burrowing into banks and dikes as it moves upstream. Damage to levees in the San Francisco Bay delta already is a concern, but the worst may lie ahead. Mitten crabs have disrupted fish passage operations in California. If repeated in Oregon, this situation could spell disaster for some of our ailing salmon stocks.

Among invasive plants, *Spartina alterniflora* is considered a pest species in Pacific Northwest estuaries. A native of East Coast tidal wetlands, it was inadvertently introduced into Willapa Bay, Washington with oysters brought from the East Coast in the early 20th century. The East Coast oysters did not do well, but *Spartina* got a foothold. Only recently has it taken off, however, increasing its range from 400 to 4,000 acres in Willapa Bay from the mid-1980s to mid-1990s.

This species is a major concern because it colonizes low tidal flats, changing the habitat of important commercial species such as oysters. A small, closely watched colony of *Spartina alterniflora* in south Tillamook County is monitored and managed by the Oregon Department of Agriculture. Might this species invade Oregon to the extent it has Washington? A hybrid relative, *Spartina anglica*, also is a significant threat, having invaded northern Puget Sound wetlands near Everett.

Another introduced estuarine species is *Zostera japonica (nana),* a dwarf eelgrass that colonizes high intertidal mudflats. From a competitive perspective, it probably is not a serious threat to native eelgrass species, which are found much lower on flats.

Nevertheless, its ecological role is poorly understood. Like native eelgrass in the lower intertidal and shallow subtidal zones, it may be used by crabs and other species as refuge when the tide is out. If so, the longer exposure to drying and heating at higher tidal elevations may prove lethal to individuals seeking refuge there instead of in native eelgrass beds.

The pathways for ANS introductions are many. Some individuals may be attached to seaweed that serves as packing material for oysters; others hitchhike on the bottoms of ships, fishing vessels, or recreational boats from other regions. By far, however, the most significant ANS source today is ballast water discharged by ships calling at Oregon ports from locations throughout the world.

Ballast water, carried in compartments or tanks inside a ship and used to adjust a vessel's trim (its level or position with respect to the water), is a virtual witch's brew of unwanted organisms, mainly microscopic plankton and larval forms of larger species (Figure 16). Scientists sampling ballast water from more than 160 ships visiting Coos Bay found more than 400 species of living nonnative organisms that ultimately were pumped into the bay. Within the South Slough of Coos Bay, scientists have documented at least 32 introduced species, 14 of which likely were introduced in ballast water.

Once established, ANS are difficult if not impossible to eradicate. The best solution to ANS problems is to avoid introductions in the first place. One preventive measure being promoted is voluntary ballast water exchange in the deep ocean after ships leave foreign ports. Shippers argue, however, that some ships are not equipped to exchange ballast water at sea and to do so would jeopardize vessel stability and safety. Other solutions, such as ballast water treatment prior to release, are technologically feasible, but probably too expensive for Oregon's small ports.

Education and management safeguards can reduce inadvertent introductions from the many other "nonpoint" sources of ANS.

Figure 16.–*Discharge of ballast water from ships visiting Oregon ports is the source of many new species introductions. (Drawing by Sharon Torvik, courtesy of South Slough National Estuarine Research Reserve)*

Recent restoration activities in Oregon estuaries

Figure 17.–Location, size, and date of dike removal for salt marsh restoration sites in the Salmon River estuary: (1) Mitchell marsh, 52 acres, 1978; (2) "Y" marsh, 200 acres, 1988; (3) Knight Creek marsh, 2 acres, 1996; (4) Salmon Creek marsh, 55 acres, 1996.

The body of knowledge and technology for estuary restoration and enhancement is growing rapidly, but there still are few carefully monitored sites. Two estuaries in Oregon where significant scientific investigation is taking place are the Salmon River estuary and the South Slough of Coos Bay.

Restoration efforts in both of these estuaries are described briefly below. References and contacts for more information are listed in the resources section. Monitoring continues at both estuaries, but results to date illustrate that significant success is possible if initial goals are realistic. Lessons learned from these and other restoration efforts are included in guidelines for restoration projects later in this chapter.

Restoring the Salmon River estuary

When Congress established the Cascade Head Scenic Research Area in 1974, one goal was the restoration of the Salmon River estuary just south of the massive headland. The tidal marshes along the estuary had been used for years for hay production and grazing. About 75 percent were diked and drained during the 1950s and 1960s to improve agricultural productivity and create pasture. Another marsh was dredged for a marina that never materialized. The rerouting and shortening of U.S. Highway 101 with a filled causeway and bridge across the estuary in 1961 caused additional major hydrologic changes to the estuary and its tributary creek system.

Salt marsh restoration projects began in 1978 with removal of a tide gate and the breaching of 17-year old dikes on the 52-acre "Mitchell" marsh parcel on the north shore (Figure 17). Scientists from Oregon State University surveyed the site prior to breaching and set up a long-term monitoring program to evaluate the restoration process, especially vegetation reestablishment.

In 1988, the entire dike was removed at the Mitchell site to allow more natural tidal flow and drainage across the site. At the same time, the 200-acre "Y" marsh on the south side of the estuary was restored by breaching and removing dikes and a tide gate at Rowdy Creek. Other restoration projects followed, including the 2-acre Knight Park marsh and the 55-acre Salmon Creek marsh in 1996. The location of each of these projects is illustrated in Figure 17.

Generally, restored marshes took several years to pass through a succession of species and develop full wetland plant cover. After 5 to 10 years, Lyngby's sedge–a common low salt and brackish marsh species–dominates much of the restored area. Restored tidal marsh vegetation seems to reach a relatively stable community about 10 to 20 years after dike removal, although vegetation does continue to change after that time.

Tidal creeks, made shallow and wide from years of grazing and the absence of tidal exchange, have deepened and narrowed. In the more mature project areas, these restored tidal creeks now resemble those in control marshes that never were altered.

In 1997, monitoring expanded to include fish utilization of restored areas, particularly by juvenile salmon. This work still is in progress, but should yield data on juvenile salmon residence times, habitat and food preferences, and growth rates in both restored marshes and unaltered reference sites. This information is vital to understanding the role of estuarine restoration in the recovery of salmon populations along the Oregon coast.

Restoring South Slough: The Winchester Tidelands Project

In the South Slough National Estuarine Research Reserve (SSNERR)–the south arm of Coos Bay–a unique experiment in integrated upland–floodplain–estuary restoration is underway. Scientists from the SSNERR, with advice from an interdisciplinary team of specialists, are restoring fresh- and saltwater marshes, eelgrass beds, tidal creeks, and channels; reconnecting historical floodplains to creeks; passively restoring long-abandoned roads and decommissioning others; and planting a mixture of native trees–fir, hemlock, cedar, alder, and maple–along slopes that have been logged as many as three times since early settlement.

The Winchester Tidelands Restoration Project (WTRP) is the coastal wetland component of the project (Figure 18). It includes a variety of passive and active tidal wetland restoration projects along Winchester Creek.

At Kunz marsh, which subsided several feet after diking at the turn of the century, an experiment is underway to determine whether manipulation of site elevation can accelerate recovery of different types of wetlands. Five experimental cells were established, and soil from the dike was redistributed within the cells to establish different base elevations. After 3 years of sampling, this project illustrates that site manipulation does result in the development of different vegetative cover and drainage. Several more years of monitoring will be necessary to more fully document site development and evolution and to draw definitive conclusions.

Active or passive restoration of other wetlands along the tidal creek is proceeding. One site–Cox Canyon marsh–is getting significant help from beavers that have recolonized the area (Figure 19).

Lessons learned at South Slough, like those at the Salmon River estuary, are proving extremely valuable to watershed groups and others seeking to restore other estuarine habitats. These lessons are incorporated into the project planning guidelines presented later in this chapter.

Prognosis for Oregon estuaries–decline or restoration?

What is the outlook for estuarine ecosystem health in Oregon? Many factors need to be considered. Population growth, demand for fresh water, coastal economic trends, efforts to control pollution and aquatic nuisance species, the integrity of plans designed to provide habitat protection, and restoration and enhancement efforts all play a role.

Oregon's 1999 permanent coastal population was about 350,000, with numbers doubling or tripling during peak tourist season. Statewide, Oregon's population is expected to swell from 3.2 million in 2000 to 4.6 million in 2020, with 80 percent of the growth in the Willamette Valley. Many new Oregonians living in the Willamette Valley will be part-time coastal residents or at least regular visitors. The permanent coastal population also will grow as baby boomers retire on the coast.

Given this projected growth, what changes might we expect for Oregon's estuaries over the next 20 to 50 years? While predictions can be risky, they are useful if taken with a grain of salt (pun intended). Recent trends suggest the following:

- Estuaries will continue to support a diversity of uses and activities, among them deep-water shipping (Coos Bay, Yaquina Bay, and the Columbia River estuary), home ports for fishing fleets, recreational fishing and marinas, charter fishing, sailing, aquaculture (oysters, clams, and

Figure 18.*–Winchester Creek marsh restoration sites: (1) Kunz marsh, with different research cells (a–e); (2) Dalton Creek marsh; (3) Fredrickson marsh; (4) Cox Canyon marsh; (5) Tracy marsh; (6) Toms Creek. (Photo courtesy of Craig Cornu, South Slough National Estuarine Research Reserve)*

Figure 19.—*Beaver have served as restoration project assistants at the Cox Canyon marsh (see Figure 18) portion of the Winchester tidelands restoration. (Photo: Jim Good)*

salmon), waterfowl hunting, birding, and other nature activities.

- Strict estuary zoning plans probably will prevent significant new dredging or filling for development.
- Increased withdrawals of fresh water by urban and rural users will change freshwater inflow to estuaries, which, in turn, will change mixing and circulation patterns, estuarine habitats, and biology.
- Fish and shellfish resources may decline due to increased harvest pressure, particularly from recreational users.
- Our understanding of the impacts of runoff pollution will increase, as will our ability to pinpoint sources and provide control technologies. Political considerations and costs will determine whether problems persist, increase, or are reduced.
- The adverse impacts of introduced species will become better known as scientists continue to study their distribution, spread, and ecological interactions.
- Estuaries probably will continue to expand, as former marsh areas are restored or revert to salt marsh after dikes or tidegates fail. This trend may lead to improved ecosystem health and increase the supply of fish and wildlife habitat, offsetting other losses.
- Estuary-related tourism and recreation will continue to increase as more people call the coast home for at least part of the year.
- Competition for limited shoreline and estuarine surface area likely will increase, with residential developers, marinas, tourist businesses, and recreational users challenging traditional users such as ports, fish processors, oyster farmers, and commercial clammers.
- Natural resource industries that use the estuary, despite decline in recent decades, still will be important economically and culturally.
- Public access to estuaries, particularly in urban areas where waterfront revitalization plans are being developed and

implemented, will continue to improve, further enhancing recreational and tourism uses.

- Urban shoreline changes will have ramifications for ecosystem protection and restoration by increasing both the awareness of the need and opportunities for ecosystem restoration and pressure to expand urban growth boundaries along the shoreline.

ASSESSING ESTUARY HEALTH AND PLANNING FOR REHABILITATION

Assessing estuary health and developing an estuary-wide rehabilitation plan are part of the overall watershed process. These steps can, however, be done independently, as long as the important upstream and watershed connections are made. A model process for evaluating estuarine health and developing an estuary-wide restoration and enhancement plan includes five steps. They are listed briefly in the sidebar and described in more detail below.

The process in the sidebar sounds relatively simple…or does it? Successfully accomplishing this process, even for a relatively small estuary, is a significant undertaking. It requires detective work to track down useful information, an understanding of how estuaries work (tides, circulation, mixing, and habitat structure), sensitivity to existing land uses and private property rights, inclusion of people who could be affected,

ESTUARY-WIDE PLANNING FOR REHABILITATION

Step 1. Assess the condition and health of your estuary.

- What were presettlement historical conditions?
- What are current estuary conditions and health?
- What are today's principal ecological problems and foreseeable threats and risks?

Step 2. Set restoration and enhancement goals.

- Considering current and historical conditions, ecological problems, and threats, what are the goals for restoration and enhancement, protection, management, research, monitoring, and public and decision maker education?

Step 3. Identify potential restoration, enhancement, management, and education projects and priorities.

- Based on results from Steps 1 and 2, what specific projects will do the most to accomplish each restoration goal?

Step 4. Screen potential projects for constraints and feasibility.

- Considering possible constraints, such as land-use conflicts, property ownership, willingness to participate, and public and private cost, what projects are realistic and cost-effective?

Step 5. Synthesize planning results, write an action plan, and begin work.

- What is the overall vision for estuary restoration, enhancement, and management?
- Commit the plan to writing, maps, and drawings; begin its implementation project by project; monitor progress; and periodically reevaluate priorities, recognizing that goals and constraints may change over time.

and incorporation of local knowledge and values. A bottom-up, team approach is needed to pull together and analyze information, to go neighbor to neighbor with proposals, and to arrive at an acceptable restoration vision. Top-down help is needed as well to help locate and interpret information and to help access financial resources.

This process may take a year or more. However, some projects will be feasible from the start and address problems that everyone agrees on. Start working on these projects as soon as possible. *Early success in implementing restoration projects is critical to building and maintaining community support and interest.*

A well-reasoned plan is important and will help you get financial support, but we all know about plans "gathering dust on the shelf." Your plan should include ways to monitor progress and publicize success stories and milestones. It also should include provisions for revising goals to address new problems, opportunities, or constraints.

Each step in this process is discussed below, with emphasis on the first–estuary assessment.

1. Assess the condition and health of your estuary.

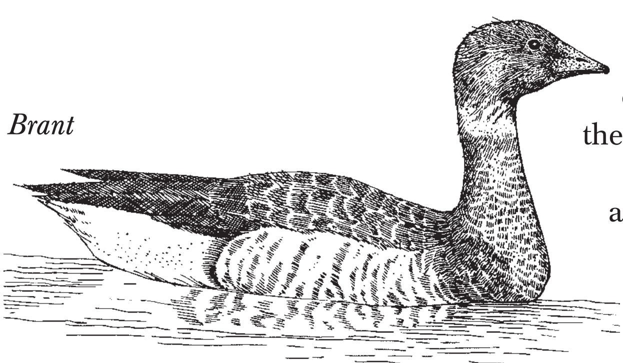
- What were pre-white-settlement conditions?
- What are current estuary conditions and health?
- What are today's principal ecological problems and foreseeable threats and risks?

A good information base is the first step in any planning process. To evaluate your estuary's health, you need a reference point. Its *ecological history* from presettlement to present provides this context.

Current conditions would seem to be the easiest part of the assessment. We have maps of existing habitats, for example, plus detailed aerial photos and at least some water-quality data.

However, you quickly will find that little published information is available that explains how your particular estuary works at the scale you seek to understand. Thus it is useful to tap into the knowledge of local biologists, other professionals, and those who spend lots of time on the estuary.

Even more challenging is trying to predict future risks and threats. Present trends offer some clues, however. For many estuaries, threats such as runoff pollution and aquatic nuisance species need to be documented.



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Each of the three questions in Step 1 is discussed in more detail below. By answering these questions, you can generate an initial list of potential restoration and enhancement projects.

What were pre-white-settlement conditions?

The purpose of researching the estuary's ecological history is to provide insight into how the estuary functioned in a relatively pristine, unaltered condition. Its purpose is *not* to try to turn back the clock to recreate these pristine conditions. Even if it were physically possible to recreate presettlement ecosystem conditions (which it is not), it would not necessarily be ecologically desirable, nor would it be realistic from a community or economic perspective. Instead, estuary restoration (and watershed restoration generally) needs to be set in the context of present conditions and the problems to be solved. (See Step 2.)

The historical conditions assessment should begin at presettlement times and continue to the present. Common physical alterations include jetty construction, stabilization and dredging of channels, filling of flats or marshes, logging of forested swamps, diking and draining of marshes, and installation of tidegates.

It will be apparent that some physical changes that have damaged or degraded estuarine ecosystems are reversible. Your task is to identify and describe opportunities to rehabilitate the estuary in ways that are consistent with present and projected economic uses and your goals for improving estuary health and functioning. For example, replacing an undersized road culvert that prevents tidal exchange into a slough with a larger culvert or small bridge would benefit the estuary without interrupting traffic flow. Restoring diked wetlands no longer used for agriculture is another example.

Other changes to the estuary clearly are not reversible. It is unlikely, for example, that jetties will be removed or dredged channels filled in.

Watershed groups can use a variety of resources to assess historical conditions and compare them to present conditions. The most recent, consistent habitat data and maps are compiled in the *Oregon Estuary Plan Book* (Table 1). The Division of State Lands can provide permit data and records on alterations since the mid-1970s (the baseline for the plan book data). You may have to search individual permit records, but the DSL resource coordinator for your region can help.

Looking farther back in time, however, is more important, since most changes in estuaries occurred in the late 19th and early to mid-20th centuries. There are many resources available to help in this task:

- *Aerial photos* dating back to 1939
- *National Wetlands Inventory* (NWI) maps, which superimpose estuarine habitats (and most diked areas) on USGS quadrangle maps
- *County soil surveys* and maps, which show tideland and other hydric soil areas
- *U.S. Coast Survey charts* dating as far back as the mid-1800s, which show channels, bottom sediment types, marsh vegetation, forested swamps, and changes such as jetties, fills, and other development (Figure 20 is an example for Coos Bay.)

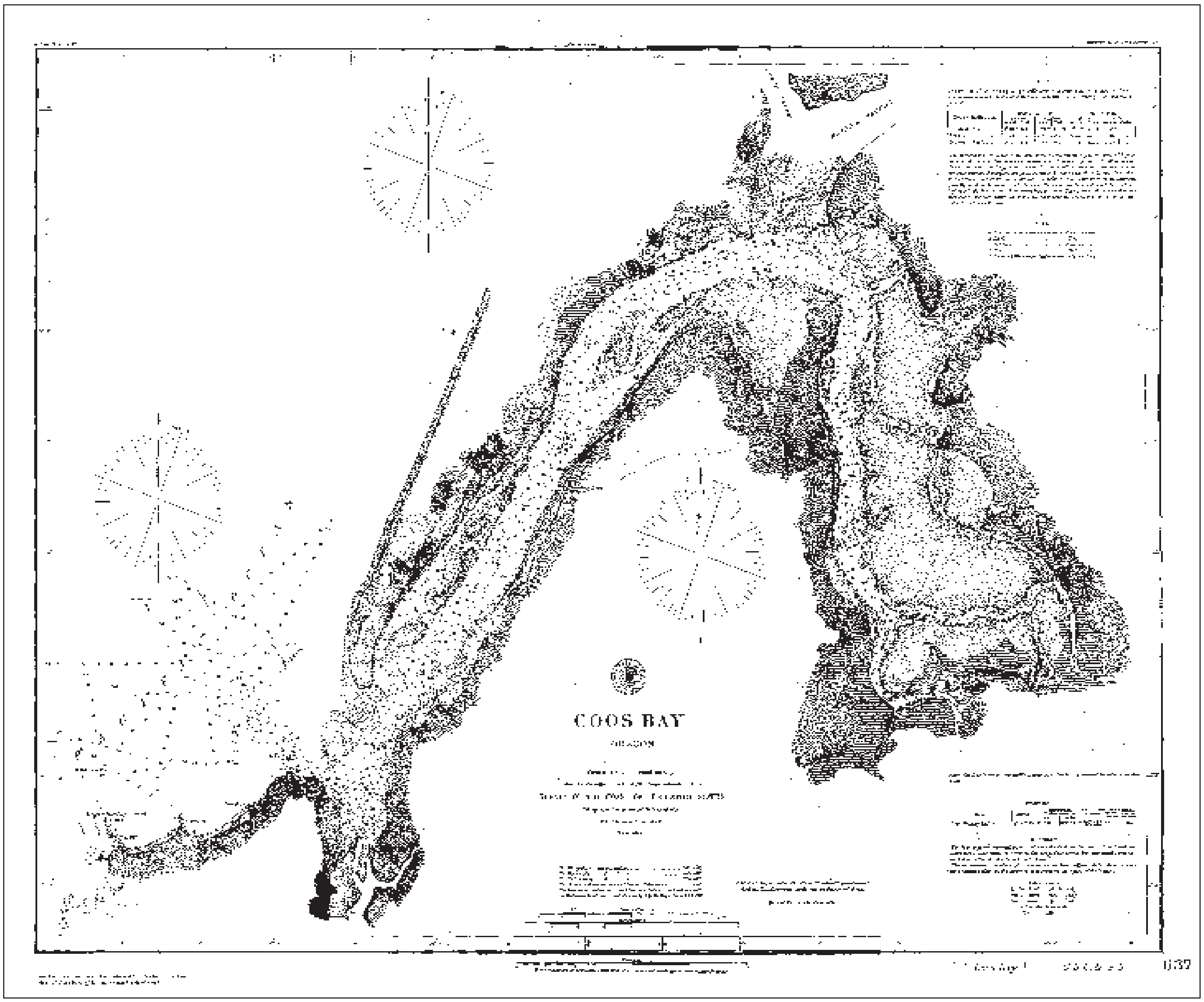


Figure 20.—*Early Coast Survey navigation chart of Coos Bay (1901), showing areas of channels, tidal flats, tidal marshes, and estuary–upland boundaries. (Source: NOAA)*

- *Original Public Lands Survey Records* from the mid-1800s, which include maps and descriptions of forested and grassy areas, tidal creeks and streams, and other landscape features
- *U.S. Army Corps of Engineers navigation and snag removal records*
- *Hydrologic and water-quality records* from state and federal agencies
- *Fisheries statistics and records* that document fish runs and harvests
- *Historical ground photos and written accounts*
- *Local diking and drainage district records*

These data sources and how to acquire them are described in more detail in Appendix A.

What are current estuary conditions and health?

A comparison between historical habitat conditions and current conditions is one indicator of estuary health. For example, changes in estuarine salt marshes and tidal creeks can be used to estimate changes in the estuary's capacity to support salmon. This information then may serve as a basis for restoration goal setting.

The extent to which remaining habitats are protected from future alterations is another important, if speculative, consideration. Generally, key Oregon estuarine habitats are well protected. Estuary plans; zoning; wildlife areas; and strict regulation of filling, dredging, pollution, and other alterations provide significant direct protection for critical habitats.

Habitat information. Two sources of relatively recent habitat information are readily available for Oregon's estuaries:

- NWI maps (described above, in Appendix A, and in Chapter II-9, "Wetlands")
- Estuary habitat maps, data tables, and digital data from the *Oregon Estuary Plan Book,* which is based on a modified version of the NWI

Recent physical alterations. One source of information is the study of 1971–1987 physical alterations of estuaries by Fishman Environmental Services. (See "Regulating dredge and fill" earlier in this chapter.) It documents recent dredge and fill projects for each estuary. To assess how well your estuary currently is protected from physical alterations, obtain copies of local estuary plan implementation ordinances and set up mechanisms for monitoring local and state permit actions on development, dredging, and filling, as well as possible violations.

Aquatic nuisance species (ANS). As noted earlier, some introduced species are welcome in Oregon estuaries. Others are not. The European green crab *(Carcinus maenus)* and saltmarsh cordgrass *(Spartina alterniflora),* for example, were discussed earlier. Many less prominent plant and animal species that have invaded Oregon's estuaries eventually may be recognized as aquatic nuisances.

As part of your estuary assessment, collect information on what is known about ANS in your estuary—the severity of infestations, potential sources of introductions, and possible control strategies. Early detection of new ANS populations sometimes allows successful control or eradication. Watershed groups can play an important role in a statewide ANS detection network.

Nonpoint source or "runoff" pollution. Because excessive pollution can derail otherwise successful restoration and enhancement efforts, it is important to identify potential pollution sources. Gathering and making sense of pollution data can be complicated. Local or headquarters DEQ staff can provide technical assistance.

Pipeline-introduced pollution is strictly regulated by the Department of Environmental Quality (DEQ) as part of the National Pollutant Discharge Elimination System (NPDES) permit program. Information on these discharges can be obtained from DEQ.

Information on broadly distributed runoff pollution from farms, forests, and rural and urban areas is much more difficult to obtain. How these pollutants affect estuarine health also is poorly understood. DEQ does have limited water-quality measurements for some estuaries. The Oregon Department of Agriculture monitors coliform counts in estuaries where shellfish are produced commercially.

Where dairy and other livestock operations are common, check with local farm organizations and OSU Extension Service agents about problems and how the watershed council can get involved in finding solutions.

Find out whether and how communities along estuary shorelines capture, treat, and discharge stormwater, and how they regulate and enforce sediment runoff controls at construction sites. Link up with local citizen monitoring efforts such as CoastNet, a program operated through high schools and middle schools along the Oregon coast, or start a citizen monitoring program.

Controlling runoff pollution is a long-term proposition requiring training, monitoring, evaluation, and problem solving. See Chapters II-5, "Riparian Functions," II-8, "Stream Evaluation and Enhancement," and II-9, "Wetland Functions and Management," for more information on water quality, runoff pollution, and actions that may reduce pollution.

What are today's principal ecological problems and foreseeable threats and risks?

As you examine historical and current estuary conditions, ecological problems will be revealed—invasive pest species, pollution sources and hot spots, restricted tidal circulation, habitat degradation, and other conditions that diminish estuarine health, functions, goods, and services. Restoration and enhancement activities and projects may help resolve these problems or at least make them less severe.

It is very important to make problem identification and goal setting a community-based process. You can use a combination of techniques to collect local viewpoints and, at the same time, present the estuary assessment information being compiled. Examples include newspaper or mail surveys, programs at meetings of local organizations, coffee klatches, and door-to-door, neighbor-to-neighbor discussions (Figure 21).

2. Set restoration and enhancement goals.

- Considering current and historical conditions, ecological problems, and threats, what are the goals for restoration, enhancement, protection, management, research, monitoring, and public and decision maker education?

As problems are identified in the community-based process discussed above, consider goals for restoring and enhancing estuary health. In meetings with local organizations and the public, present findings of the health assessment (Step 1) and facilitate discussion to identify estuary problems, restoration opportunities, and goals for improving the estuary.

Setting goals is relatively simple once there is a consensus about key problems. Simply turn problem statements from negative to positive to create a goal. Before finalizing goals, present them to the community and ask for feedback. This process takes time, but it is worthwhile in terms of building community and property owner support and understanding.

Figure 21.*—Local workshops are one way to survey available information and set goals for restoration. (Photo: Jim Good)*

3. Identify potential restoration, enhancement, management, and education projects and priorities.

Based on results from Steps 1 and 2, what specific projects will do the most to accomplish each restoration goal?

The next step in developing a realistic estuary action plan is to screen restoration and enhancement opportunities identified in Step 1 for their potential to help solve problems and achieve the goals identified in Step 2. This process requires a careful, even tedious, examination of each project as it relates to each goal.

It may be useful to create a large matrix of opportunities (project sites) versus goals. Give each site a rating of 1 to 5 (high to low) for its ability to meet each goal. Then add up all of the ratings for each site to establish site priorities. Some goals may need to be weighted more heavily than others, depending on their relative importance. This sort of process can be helpful, but needs to be supplemented by good judgment and common sense.

4. Screen potential projects for constraints and feasibility.

- Considering possible constraints, such as land-use conflicts, property ownership, willingness to participate, and public and private cost, which projects are realistic and cost-effective?

The result of Step 3 is a set of site priorities based on the match between restoration/enhancement opportunities and goals. However, other constraints need to be factored into a final set of priorities. For each on-the-ground project or proposed action, ask the following questions:

- Are there potential land-use conflicts?
- Who owns the property?
- Is the property owner willing to sell or donate the property?
- How do neighbors feel about the project?
- How much will the project cost?
- Where will the money and labor come from to actually implement and monitor the project?

Answers to some of these questions may drop some sites or projects off the list immediately. Project feasibility may change over time; what is not feasible today may be feasible 5 years from now, for example, if land ownership changes or funding becomes available.

Some projects may involve working to get land-use or water-quality rules changed so that otherwise feasible on-the-ground projects can go forward. In Coos Bay, for example, reservation of a diked wetland for use as future development mitigation made it ineligible for nonregulatory restoration, even though it was owned by the South Slough National Estuarine Research Reserve. The county changed the rule to allow habitat restoration for research purposes, but similar constraints exist in other estuaries.

5. Synthesize results, write an action plan, and begin work.

- What is the overall vision for estuary restoration, enhancement, and management?
- Commit the plan to writing, maps, and drawings; begin its implementation project by project; monitor progress toward its accomplishment; periodically reevaluate priorities, recognizing that goals and constraints may change over time.

The action plan developed to this point is a vision for improving an estuary's health and condition. Document your planning process and decisions with maps and text.

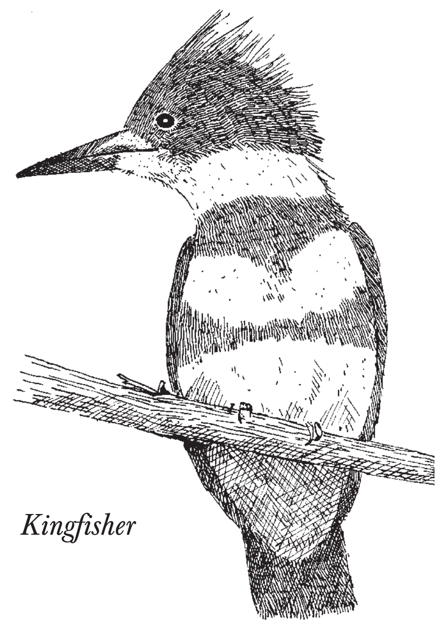
RESTORING THE ESTUARY– PROJECT BY PROJECT

An estuary-wide action plan developed using the process described above will yield specific, high-priority projects to achieve estuary and watershed goals and will have community and property owner support. The next step–actually constructing and monitoring projects–is the rewarding part. But it is not so simple as breaching dikes or installing new culverts. Project by project, you must survey sites, set realistic goals, make drawings of present and projected conditions, secure funding and equipment, undertake construction, and begin monitoring. The needs associated with any given project will vary, but all require the same general steps.

There is a growing body of knowledge about how to best restore or enhance estuarine habitats and functions. Particularly valuable for Oregon are lessons learned from more than 20 years of salt marsh restoration in the Salmon River estuary and the restoration of a variety of habitats in the South Slough of Coos Bay.

From these experiences and other restoration and enhancement projects in the Columbia River estuary, Washington, and California, it's possible to derive a general process and set of principles for carrying out estuary restoration or enhancement projects. This process is outlined below as four steps:

1. *Project planning and design*
2. *Project construction*
3. *Monitoring*
4. If needed, *project modification* to correct problems or revise goals to be more consistent with actual site potential.



Kingfisher

This kind of approach often is called *adaptive management,* meaning that we recognize our limited ability to predict outcomes and thus treat every project as an experiment.

1. Project planning and design

Planning and design considerations for estuarine restoration or enhancement projects vary by project type. However, some general aspects of project planning and design are similar for all projects. First, a thorough assessment of historical and current site conditions is needed. Next, clear goals and objectives–consistent with site potential and expected restoration trajectory–must be set. Finally, a monitoring plan is needed for estimating progress toward goals and suggesting corrective actions as needed.

Beyond these general considerations, each type of restoration project and each individual project will have unique design considerations. Establishment of salt marsh vegetation on a dredged material island, for example, will have different design specifications than an eelgrass planting, clam bed restoration, or culvert replacement.

The project used here to illustrate design considerations is a *tidal marsh restoration*–a common opportunity in Oregon's estuaries, given the extensive wetland diking and draining that took place early in the 20th century. Many factors listed here are purely physical considerations, reflecting the perspective that if you restore appropriate hydrology and landscape conditions, the biology will follow. But biological considerations also are important in planning.

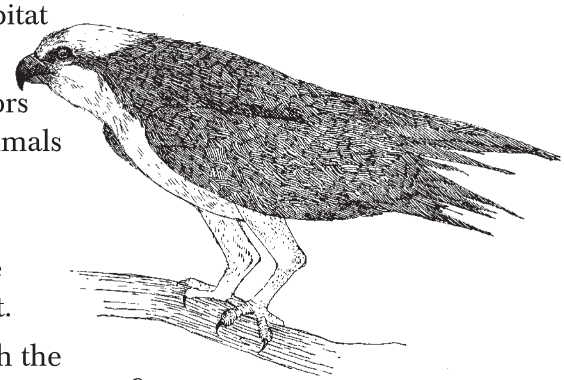
Based on previous tidal marsh restoration experience in the region, the following design principles and planning considerations are recommended. They can serve as a checklist for groups undertaking similar projects.

☐ *Watershed disturbances*–Consider existing or potential upland and upstream disturbances when designing estuarine restoration or enhancement projects.

☐ *Links to other projects*–Consider opportunities to simultaneously plan and construct estuarine, upstream, riparian, and upland enhancement projects to increase effectiveness and efficiency at the watershed level.

☐ *Buffers*–Minimize boundaries shared with developed areas that will disturb wetland wildlife or interfere with desired functions or values. Where such boundaries are unavoidable, plan for adequate buffers between the wetland and adjacent development.

- ☐ *Size*–Large estuarine restoration projects are, in general, preferred over small projects because of their potential habitat and functional diversity.
- ☐ *Corridors*–Consider the need for water and wetland corridors between separated habitat areas so wildlife and aquatic animals can move from one area to another.
- ☐ *Energy regime*–Carefully consider the site's energy regime. Exposure to excessive tidal currents and wave action is the most frequent reason for failure of vegetation development.
- ☐ *Manipulation*–Minimize manipulation of the site. Work with the site to take advantage of its natural configuration, drainage, and other characteristics. Extensive manipulation is expensive and prone to failure.
- ☐ *Sustainability*–Plan for self-sustaining habitats, thus minimizing maintenance costs.
- ☐ *Subsidence*–Because diked and drained tidal marshes subside a foot or more and may continue to utilize unnatural drainage patterns after dike removal, complete restoration to former, pristine conditions is not a realistic goal. However, restoration to a well-functioning part of the estuarine ecosystem is realistic.
- ☐ *History*–Historical conditions at and surrounding the site may or may not be a good predictor of site restoration potential, given past alterations. However, understanding the history of the site and its likely prediking elevations and habitats will provide clues that are useful in setting goals, designing the project, and understanding limitations.
- ☐ *Prerestoration survey*–A careful prerestoration survey of historical channels and creeks, present drainage patterns, adjacent tidal and salinity regimes, water quality, soil characteristics, and land elevations is important for setting realistic restoration goals and developing a monitoring program. Also survey nearby intact reference sites to serve as control sites.
- ☐ *Hydrology*–Restoring prior hydrologic connections is critical to successful restoration. If possible, completely remove dikes. Open tidal creeks at their former locations and dredge them to ensure adequate tidal exchange.
- ☐ *Vegetation*–Vegetation reestablishment can be passive if there are nearby "seed bank" tidal marshes of the type expected to develop at the restoration site. Planting is expensive and usually unnecessary for tidal wetlands. If vegetation does need to be planted, use local plants or seed stock, and pay careful attention to site elevations, slopes, energy regime, tidal influence, salinity regime, and freshwater input.



Osprey

- ☐ Permits–You will need a permit from the Division of State Lands and the Corps (and possibly the city or county) to construct your project. (See “Resources.”) Involve them early. Specialists from these and other agencies, such as the Oregon Department of Fish and Wildlife, and from nongovernmental agencies and universities also can be helpful.

2. Project construction

After you complete the site assessment, planning, and design and secure funding, construction can begin. The following considerations and principles are important:

- ☐ Follow construction plans–Construction should follow the site plan exactly. Next to poor planning, construction that did not meet specifications is the most common cause of failed restoration and enhancement projects. Wetland specialists and engineers should be onsite during construction to ensure plans are followed.
- ☐ Salvage materials–Construction should be phased to allow salvaging of vegetation and substrates of ecological value.
- ☐ Timing–Time construction to accommodate the tide cycle and seasonal cycles of vegetation growth and fish and wildlife activities.

3. Monitoring

The importance of monitoring a site after it has been manipulated for restoration or enhancement cannot be overemphasized. Every estuarine restoration or enhancement project should be monitored at some basic level (Figure 22). Monitoring lets you know whether you are moving along the projected restoration trajectory and suggests ways of correcting problems that inevitably arise. Monitoring also can be used to set more realistic goals and improve the design of future projects.

Monitoring has both short- and long-term considerations. In the short term, monitor drainage pattern development, sedimentation and erosion, fish and wildlife use, and vegetation establishment. In the long term, the concern is whether the estuarine habitat has become a well-functioning, integral part of the estuarine ecosystem.

Plans for post-restoration monitoring vary depending on the size, scope, and goals of the project; the purpose of monitoring; and the training, skills, and time available. *Basic monitoring,* which can be carried out by trained volunteers and/or watershed council members with engineering, map-making, and other skills, may include:

- ☐ *General photo documentation*–Take photos from established locations before, during, and immediately after construction.
- ☐ *Construction assessment*–Create plan views, cross-section maps, and drawings to ensure that construction follows plans.
- ☐ *Physical site development*–Use periodic photo documentation and mapping to follow the evolution of drainage patterns, tidal connections, tidal creeks, undesirable ponding, and, if possible, sedimentation and changes in elevation (monthly at first, quarterly later).
- ☐ *Vegetation*–Continue photo documentation, mapping, and description of vegetation development and succession, including percent cover, species composition, and distribution. If relevant, compare success of planted areas with natural recruitment (quarterly).
- ☐ *Water quality*–Monitoring estuarine salinity and water quality requires specialized equipment and training, but your group can work with local schools who are part of the CoastNet water-quality monitoring program. (See "Resources.")
- ☐ *Aquatic life use*–Describe initial colonization, succession, and use of tidal flats, tidal creeks, channels, and marsh surface by bottom-dwelling plants (e.g., eelgrass and algae) and animals (amphipods, worms, clams, and fish such as juvenile salmon, trout, and skulpin), land and aquatic mammals (seasonal for at least a full tidal cycle and dawn and dusk period), and birds (seasonal for at least a full tidal cycle). Sediment cores and sieves, fish nets, traps, and visual inspection are useful techniques. While resulting data may not be statistically accurate, these methods can give a good overall view of changing site use by estuarine organisms.
- ☐ *Recreation use*–Evaluate the site for recreational use, including levels of disturbance and effectiveness of established buffers.

The above monitoring guidelines are the ideal but are unrealistic for many projects because people, funds, or equipment may not be available. The extent of monitoring should be related to the level of investment in the project, its importance, the risk of failure, and so on.

Figure 22.–*Setting up a monitoring grid is the first step in tracking changes at a restoration site. (Photo: Robert Frenkel)*

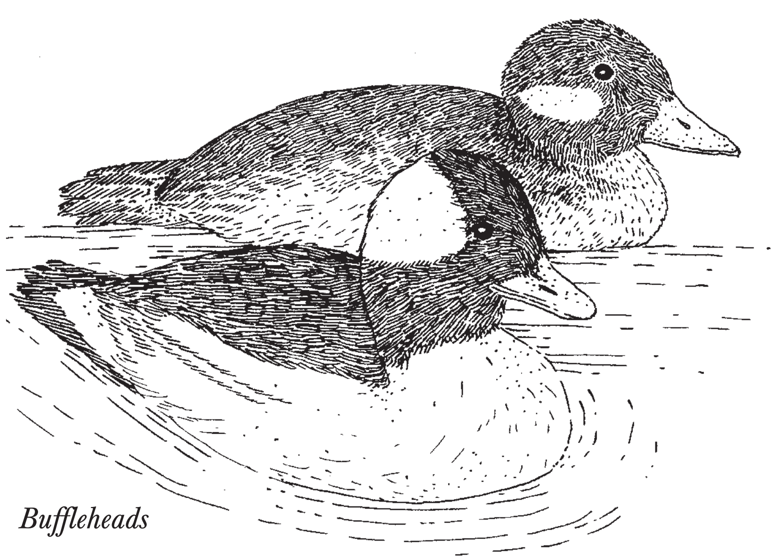
In some cases, even more in-depth monitoring may be desirable. In this case, professionals and scientists probably already are involved. In-depth technical monitoring, such as calculating sedimentation rates, analyzing sediment salinity, measuring plant biomass, quantifying use of the site by endangered species, and evaluating food and habitat preferences, generally is carried out by professionals and scientists.

How long should monitoring continue? Research on estuarine restoration and enhancement the past 20 years suggests that determining "success" requires at least 10 years of postrestoration monitoring, both because sites take time to develop and because needed corrective actions may not be apparent over shorter time periods. Few watershed council projects are monitored formally for this long. However, productive partnerships with schools, hunting or fishing organizations, and other groups may allow longer term tracking of project success.

Whatever the proposed level of monitoring, it is advisable to secure technical assistance before initiating monitoring. Resource specialists and scientists from agencies and universities can help outline a program and train local volunteers.

4. Practicing adaptive management

If monitoring shows the project is not proceeding as planned, physical or other modifications may be needed. Alternatively, you may need to modify project goals to be more realistic and consistent with the site's actual potential to perform desired functions.



Buffleheads

Summary/Self review

Estuaries are transition ecosystems characterized by sheltered wetlands, tidal flats, strong tidal mixing of salt water and fresh water, and an assemblage of plants and animals adapted to highly variable conditions.

Estuaries provide a variety of valued goods and services–fish and wildlife habitat; food production that supports the estuarine food chain; water-quality maintenance; moderation of floodwater flows; shoreline stabilization; and a variety of economic, recreational, and educational benefits.

To maintain and increase the benefits estuaries provide to people and the environment, we need to:

- Protect the critical remaining estuarine habitat.
- Restore former or degraded estuarine habitats where feasible.
- Link estuarine restoration actions to upland and upstream restoration and enhancement efforts for a whole-watershed approach.
- Monitor water quality, clean up existing pollution problems, and prevent new pollution that cannot be readily assimilated.
- Avoid inadvertent or intentional introduction of harmful, nonnative plants and animals.
- Incorporate both local knowledge and the best available scientific information into our planning, decision making, and projects.
- Support research to improve understanding of estuarine ecosystems and their relationships to marine and freshwater systems.

Estuary-wide planning for restoration involves five key steps:

1. Assessment of historical conditions, current conditions, and threats
2. Setting restoration and enhancement goals
3. Identifying potential restoration, enhancement, management, or education projects and setting priorities
4. Screening potential projects for constraints and feasibility
5. Synthesizing planning results, writing an action plan, and beginning work

The purpose of studying an estuary's ecological history is to understand how the estuary functioned in the past, how it has been changed, and how it might be rehabilitated to better serve economic and ecological functions.

Experience with estuary restoration and enhancement projects in the region suggests that careful planning and design, clear goals, construction that follows plans exactly, and follow-up monitoring are keys to success.

EXERCISE

You can do this exercise on your own, but it is helpful to work in a small group so you can pool your observations.

Constructing a map of former estuarine habitats

This exercise will familiarize you with the habitat information that can be gleaned from a variety of recent and historical data sources. (See Appendix A.) You will find that not all sources are available for all parts of all estuaries. The end product will be two maps showing distribution of salt- and freshwater tidal marshes, tidal forested swamp, tidal flats, deeper channels, and other habitats. One map will show present conditions, the other historical conditions (Figure 23).

Select a relatively small area of an estuary that has been obviously altered by diking, filling, or other human actions. Obtain as many of the following information sources as possible, using the "Resources" section and Appendix A to locate them:

- The National Wetlands Inventory (NWI) "quad sheet" for the area (See Chapter II-9, "Wetlands," for ordering instructions.)
- Recent, and if available, historical aerial photos at no smaller than 1:24,000 scale (same as NWI maps)
- The county soil survey and instructions for locating hydric (wet) and tideland (former estuary) soils
- If available, old U.S. Coast Survey charts for the estuary (and information on how to interpret map symbols)
- Original Public Lands Survey records for the area (optional, but may be especially important if they are the only good early historical source)
- U.S. Army Corps of Engineers navigation records, if available
- Historical ground photos, written accounts, and local diking and drainage district records (Local and state historical societies are good sources.)

Using these sources, two blank sheets of transparent, gridded mylar (registered to the NWI map with tic marks in the corners), and a set of transparent colored pens, develop both present and historical habitat maps, using the following steps to guide the process:

1. Affix one of the mylar overlays to the NWI map with masking tape. Using appropriate colors, identify estuarine and tidal freshwater wetlands and deep-water habitats such as salt marshes (light green), tidal freshwater marshes (medium green), tidal forested wetlands (dark green), eelgrass beds (very light green), tidal flats (beige to brown), and deep-water channels and tidal creeks at low tide (light blue). See Chapter II-9, "Wetlands," for detailed information on the NWI.
2. Using the most recent aerial photos for the area (ideally 1:24,000 scale, so you may need to make reduced or enlarged copies), examine the first overlay with NWI data superimposed. Are any errors in the NWI apparent? Do the wetland boundaries seem accurate? Make changes as needed.
3. At low tide, conduct a rapid field check, looking for changes since the aerial photos used to develop the NWI, or your more recent photos, were taken. Again, correct your map as needed. The resulting *current estuary habitat* map is your first product.
4. Obtain the soil survey sheet (normally 1:20,000 scale) for the area, make an overhead transparency copy of it (reduce to 80 percent to get 1:24,000 scale), and overlay it on the NWI map. How do the

boundaries for hydric and tideland soil types compare to present estuarine wetland boundaries? Does the NWI map contain clues such as notations that a freshwater, nontidal marsh adjacent to the estuary is diked? Are tidegate locations apparent, and are dikes across former tidal creeks clearly visible? Based on soils and NWI maps and codes, estimate the former extent of tidally influenced areas and the types of habitat that may have been present. Pencil in your results on the second mylar sheet.

5. Three other sources of data may provide further clues to historical habitat types and distribution–old Coast Survey charts (Figure 20), original Public Lands Survey records, and old ground photos. The old charts show vegetation types along the shore and in wetlands, helping to differentiate forested upland from forested swamp and tidal swamp from tidal marsh.

6. From an analysis of these data sources, draw a map of historical habitat conditions for your site on the second mylar sheet, with appropriate notes and qualifiers. Calculate the area of former estuarine habitat types (e.g., tidal swamp, marsh, flats, and subtidal areas) by counting grid cells on the mylar overlay and converting to acres of habitat.

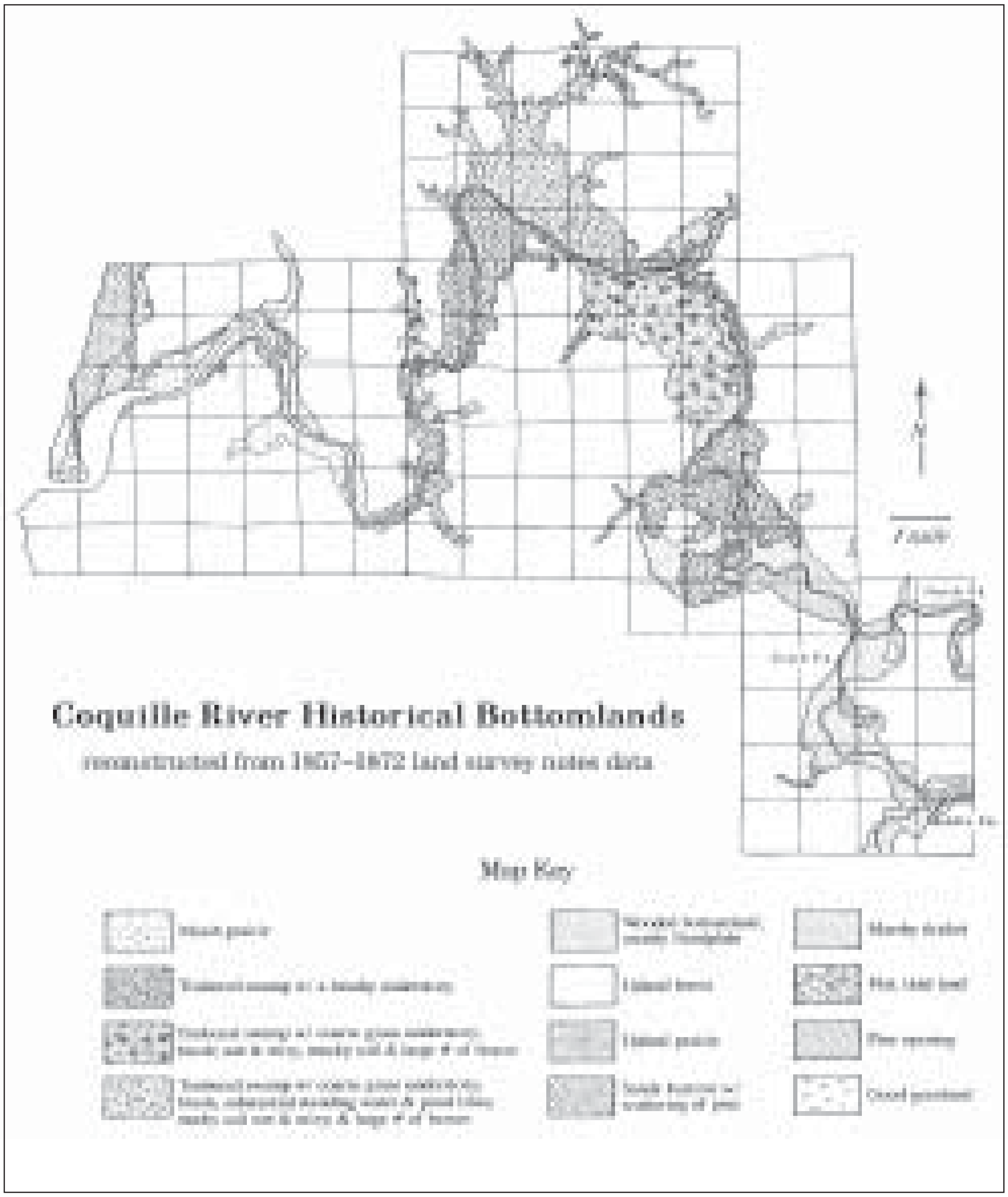


Figure 23.–*Reconstruction of historic vegetation patterns from old maps and public lands survey records was a valuable source of data for identifying potential estuarine restoration projects in the Coquille estuary. (Map courtesy of Patricia Benner)*

Resources

Technical agencies and information sources

South Slough National Estuarine Research Reserve (SSNERR)
P.O. Box 5417
Charleston, OR 97420
Phone: 541-888-2581, Ext 301 or 302
Contact: Craig Cornu or Steve Rumrill
E-mail: ccornu@oimb.uoregon.edu or srumrill@oimb.uoregon.edu
Web: http://www.southsloughestuary.com/

Oregon Coastal Management Program
Department of Land Conservation and Development
635 Capitol Street NE, Suite 150
Salem, OR 97301
Phone: 503-373-0050
Contact: Don Oswalt
E-mail: don.oswalt@state.or.us
Web: http://www.lcd.state.or.us/coast/index.htm

Oregon Department of Fish and Wildlife, Marine Division
Hatfield Marine Science Center
Newport, OR 97365
Phone: 541-867-4487

Oregon Division of State Lands
775 Summer Street, NE
Salem, OR 97310
Phone: 503-378-3805
Contact: Larry Devroy
E-mail: larry.devroy@dsl.state.or.us
Web: http://statelands.dsl.state.or.us/wetlandsintro.htm

U.S. Environmental Protection Agency, Coastal Ecology Laboratory
Hatfield Marine Science Center
Newport, OR 97365
Phone: 541-867-4040

U.S. Fish and Wildlife Service
Oregon Coastal Refuges
2127 SE OSU Dr.
Newport, OR 97365-5258
Phone: 541-867-4550
Contact: Roy Lowe, Manager
E-mail: roy_lowe@fws.gov

Education programs and facilities

South Slough National Estuarine Research Reserve (SSNERR)
P.O. Box 5417
Charleston, OR 97420
Phone: 541-888-5558
Contact: Tom Gaskill
E-mail: tgaskill@harborside.com
Web: http://www.southsloughestuary.com/

Sea Grant Extension Oceanography
College of Oceanic and Atmospheric Sciences
104 Ocean Admin Building
Oregon State University
Corvallis, OR 97331-5503
Phone: 541-737-1339
Contact: Jim Good
E-mail: good@oce.orst.edu
Web: http://seagrant.orst.edu/

Hatfield Marine Science Center
2030 S. Marine Science Drive
Newport, OR 97365
Contact: Janet Webster, librarian
Phone: 541-867-0108
E-mail: janet.webster@hmsc.orst.edu
Web: http://www.hmsc.orst.edu

Videos

Estuaries: Oregon's Coastal Treasures (available from Oregon Department of Fish and Wildlife)

Strangers in Our Waterways, VTP 023 (Oregon State University, Corvallis, 1995).

Tide of the Heron (available from South Slough National Estuarine Research Reserve)

Publications

Field Trip Guide to South Slough National Estuarine Research Reserve (available from South Slough National Estuarine Research Reserve)

Oregon Estuary Plan Book, 1987 (available from the Oregon Department of Land Conservation and Development)

Planning and Evaluating Restoration of Aquatic Habitat from an Ecological Perspective, IWR Report 96-EL-4 (1996, available from the U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA 22135-3868)

South Slough National Estuarine Research Reserve publication series, written by K. Oberrecht and illustrated by S. Torvik:
- *Salmon and Trout in Oregon Estuaries*
- *Native Shellfish and Introduced Species in Oregon Estuaries*
- *Oregon Salt Marshes*
- *Flooding on the Oregon Coast*

Web sites

USGS digital orthophotos and other products
http://www-nmd.usgs.gov/esic/esic.html

CoastNet, local schools water-quality monitoring program, some data for some estuaries
http://secchi.hmsc.orst.edu/coastnet

The Nature Conservancy's heritage sites
http://www.heritage.tnc.org/nhp/us/or/

South Slough National Estuarine Research Reserve site, with information on the Winchester Tidelands Restoration Project
http://www.southsloughestuary.com/

North Oregon Joint Ventures Wetlands Plan. Focus is on restoration.
http://wetlands.dfw.state.or.us/plan.htm#

U.S. Fish and Wildlife Service Refuges; includes Oregon coast
http://www.nationalgeographic.com/refuges

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National Estuarine Inventory: Supplement 1: Physical and Hydrologic Characteristics: The Oregon Estuaries (National Oceanic and Atmospheric Administration, Strategic Environmental Assessment Branch (NOAA-SEA), Rockville, MD, 1988).

"Oregon CZM Profile: Protection of Estuaries and Coastal Wetlands," unpublished report prepared as part of the National CZM Effectiveness Study, by J.W. Good (1997). Available for $3.00 from OSU; e-mail jburck@oce.orst.edu

Oregon Estuaries (Division of State Lands, Salem, OR, 1973).

"Oregon Estuarine Conservation and Restoration Priority Evaluation: Opportunities for Salmonid Habitat Enhancement in Oregon's Estuaries," by A. Lebovitz, unpublished manuscript, prepared for Oregon Trout and the U.S. Fish and Wildlife Service (Portland, OR, 1992). 92 pp.

Oregon Estuarine Invertebrates: An Illustrated Guide to the Common and Important Invertebrate Animals, FWS/OBS-83-16, by P. Rudy, and L.H. Rudy (U.S. Fish and Wildlife Service, Department of Interior, 1983).

Oregon Estuary Plan Book, by R. Cortright, J. Weber, and R. Bailey (Oregon Department of Land Conservation and Development, Salem, 1987). Also accessible on the Web at http://www.interrain.org/

Restoration of the Salmon River Salt Marshes: Retrospect and Prospect, Final Report to the USEPA, by R.E. Frenkel and J.C. Morlan (Oregon State University, Corvallis, 1990).

Restoration Potential of Diked Estuarine Wetlands in Washington and Oregon, Phase 1: Inventory of Candidate Sites, EPA 910/9-88-242 (U.S. Environmental Protection Agency, Wetlands Section, Water Division, USEPA Region 10, 1988).

Salmon and Trout in Oregon Estuaries, by K. Oberrecht (South Slough National Estuarine Research Reserve, Charleston, OR, 1998).

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself ahead in understanding the key concepts of estuarine science, management, and restoration.

1.

2.

3.

Appendix A–Sources of historical information about Oregon estuaries

Aerial photos

The earliest aerial photos of the Oregon coast date from 1939, but they cover only the immediate coast and do not extend upriver. More recent aerial photos are available, and some can be downloaded from the Internet. For example, USGS digital orthophotos and other products are available at http://www-nmd.usgs.gov/esic/esic.html. 1986 color aerial photos of all major estuaries are available from the Department of Land Conservation and Development's Ocean and Coastal Management Program. Although somewhat dated, these photos are very useful because of their clarity and upstream coverage to the head of tide. Other estuary photos are available from other government and private sources.

National Wetlands Inventory (NWI)

NWI maps and data, described in Chapter II-9, are available from the Oregon Division of State Lands. These maps are based on expert interpretation of aerial photos dating from the 1970s. They provide a wealth of information, showing existing estuarine wetlands, for example, as well as diked wetlands, some of which are potential restoration sites. NWI maps are a valuable complement to the *Oregon Estuary Plan Book* maps referred to earlier because they include the entire aquatic ecosystem.

County soil surveys

Soil survey maps and soil descriptions help delineate the extent of former tidelands, thus indicating what areas might be subject to tidal inundation if dikes were removed or culverts installed or enlarged. These surveys are available from the local Soil and Water Conservation district office or the OSU Extension Service.

U.S. Coast Survey charts

Topographic surveys (T-sheets), hydrographic (bathymetry) surveys, and composite charts from the late 19th and early 20th century are available for some estuaries. (Figure 20 is a sample for Coos Bay.) These maps, along with interpretation aids in government publications, provide surprisingly accurate geographic data showing pre-alteration conditions of tidal marshes, forested swamps, and flats, as well as changes in channels and estuary volume due to sedimentation.

Original Public Lands Survey records

In the middle of the 19th century, the Government Land Office conducted a mile-by-mile Public Lands Survey of much of Oregon, including coastal lowlands surrounding estuaries and upstream areas. These surveys used the familiar township-range system found on present USGS topographic maps. The old survey records are available from the Bureau of Land Management on microfiche. These records can be used to reconstruct habitats in and around estuaries and other areas. Figure 23 is an example for the Coquille estuary.

Except for the Tillamook Bay area, there are no comprehensive reconstructions of Oregon estuarine conditions using the PLS system records. However, for restoration site planning, site-specific maps and survey notes can be quite useful in evaluating historical drainage patterns and vegetation.

Appendix A, continued

U.S. Army Corps of Engineers navigation records

The Corps of Engineers has long been responsible for keeping estuaries and rivers navigable. They have dredged, built water-control structures, and cleared snags from river and estuary channels since the mid-1800s. The Corps keeps excellent records, which have been used to help reconstruct former estuarine and river conditions. These records for Oregon are available from the Portland District of the Corps.

Hydrologic and water-quality records

A change in the amount or timing of freshwater inflow to estuaries changes the makeup of the estuarine ecosystem, altering the turbidity maximum as well as plant and animal communities. The Oregon Water Resources Department and USGS are good sources of hydrologic information, and the Oregon Department of Environmental Quality maintains water-quality records. Only recent records are available, but they are important complements to historical habitat information from other sources.

Fisheries data and records

Compilations of fish catches and processing records are another useful source of data. Some data are available from the National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) and some from the Oregon Department of Fish and Wildlife. Still others are available in university libraries, for example, at OSU's Valley Library and the OSU Hatfield Marine Science Center Branch Library in Newport. Librarians there can assist you.

Historical ground photos, written accounts, local diking and drainage district records

Local records available from state and county historical societies are another good source of information. Local diking districts, map collections at university libraries, and local "old-timers" are other useful sources.