The Coastal Connection: assessing Oregon estuaries for conservation planning.

Mouth of Salmon River, Oregon. © Allison Aldous 2007.

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ABSTRACT

Oregon estuaries are an ecologically important interface between coastal watersheds and the Pacific ocean. They harbor a rich diversity of species, including salmon, Dungeness crab, benthic invertebrates, brant geese, migrating shorebirds, and many species of rock fish. The Nature Conservancy in Oregon seeks to conserve the diversity of these ecosystems. To do so, Conservancy scientists work with partners to develop conservation plans that identify strategies to abate critical threats and increase ecosystem resilience. Central to these plans is the development of key attributes of the ecosystems, and measures of those attributes, that can be monitored to quantify the viability of the estuaries as well as their response to restoration activities or other strategies. The goal of this assessment was to develop attributes, indicators, and measures of Oregon estuarine ecosystems that could be used throughout the entire coast (with the exception of the Columbia River). We identified four attributes: estuarine hydrologic circulation, sedimentation, habitat extent and distribution, and water and sediment quality. For each attribute, we developed conceptual ecological models, indicators, and measures of those indicators. We also identify key threats to the attributes. We conclude the report with a discussion of salmon use of Oregon estuaries, and how these planning products for the larger estuarine ecosystems apply to salmon conservation and recovery.

INTRODUCTION

Estuaries along the Pacific coast of North America are an ecologically critical interface between the marine and inland freshwater and terrestrial environments (ODLCD 1987). These ecosystems and their highly productive tidal wetlands provide habitat for keystone species such as anadromous salmonids and brant geese, as well as economically important shellfish. At the same time, many estuaries in the Pacific Northwest, particularly the larger ones, are threatened by habitat loss, altered sediment regimes, poor water quality, invasive species, over-harvest of fish and shellfish, sea level rise, and/or levees and tidegates that impede tidal flow.

The Nature Conservancy seeks to conserve biological diversity in estuarine habitats by developing conservation strategies, such as protection and restoration, to abate threats to estuaries and estuary-dependent species such as salmonids. To develop effective strategies, it is critical to describe the spatial extent of key estuaries, their component biodiversity, and the threats to that biodiversity. To compile this information, the Conservancy has developed a series of planning tools that are used at a range of spatial scales.

At the most coarse scale, ecoregional assessments are used to gather spatially explicit data and information for a large suite of species and ecosystems for all characteristic biodiversity across the entire ecoregion. At the finest spatial scale, conservation planners use data and information from the ecoregional assessments to develop conservation strategies for one site which can often be at the scale of a watershed. However, the level of detail and amount of information required to complete a rigorous conservation plan for one site is much greater than that generated for the entire ecoregion, and so planners either spend a lot of time gathering more specific information, or else the plan is done without that information. To address this issue, an intermediate step can be inserted into the planning process where data and information that can be used for planning at sites that share species and ecosystems within an ecoregion can be gathered and summarized. This approach ensures that planning at similar sites is done from a common baseline, that economies of scale are gained by more thorough research done for multiple sites, and that information is available to partners who wish to implement conservation strategies at sites where TNC is not working.

The objective of this assessment was to use the Conservancy's conservation planning methodology to produce planning products at the intermediate spatial scale, for estuaries in Oregon within the Pacific Northwest Coast ecoregion (excluding the Columbia River estuary). Those planning products include a compilation of data and information on Oregon estuaries, conceptual ecological models of some key ecological attributes of those estuaries, and suggestions of indicators for measuring the viability of those attributes and thus of the species and ecosystems. This assessment is intended to be used as a framework for conservation planning at the finer spatial scale of a particular estuary or small group of estuaries.

The emphasis of this assessment is on the key processes in estuaries that must be maintained for the estuary to function in an ecologically viable way. We assume that this ecological functionality must be in place to sustain viable populations of economically and culturally important species such as salmonids (Bottom et al. 2005). This does not assume that if the estuaries themselves are viable, the salmon populations will be too. The biological needs of the diversity of salmon species in the Pacific Northwest extends from headwater streams to the open ocean and is beyond the scope of this assessment.

METHODS

This section describes the four stages of the project. First, we describe the products from the Pacific Northwest Coast ecoregional assessment that were used as a starting point for this regional estuaries assessment. Second, we describe the geographic boundaries of the assessment. Third, we describe the steps of conservation planning and the products generated from this type of regional assessment. Fourth, we describe the methods used to develop the products for this specific assessment.

1. Setting the Stage: Ecoregional Assessment

The first stage in gathering information for estuary conservation in Oregon was done in a multi-partner ecoregional assessment of the Pacific Northwest Coast ecoregion (Vander Schaaf et al. 2006). This assessment identified a portfolio of sites that, if protected, will contribute to the long-term survival of the suite of native plant and animal species and ecosystems, that characterize the biodiversity of the ecoregion.

The final portfolio identified by the ecoregional assessment included most estuaries in Oregon as conservation priorities (Figure 1).

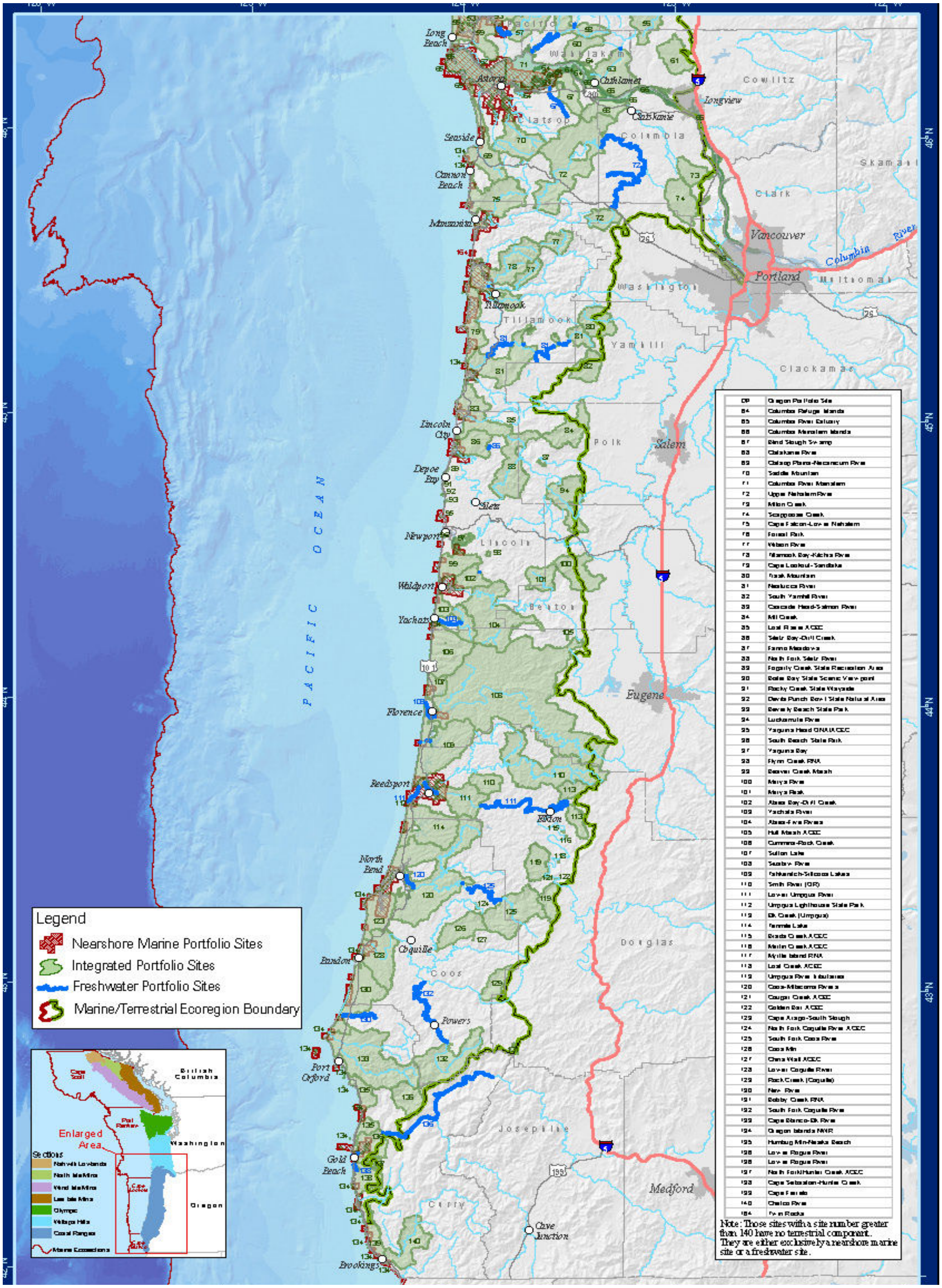


Figure 1. Final expert-reviewed integrated portfolio for the Pacific Northwest Coast Ecoregion (Vander Schaaf et al. 2007)

Along the Oregon coast, 33 estuaries were included in this list , comprising 89,281 ha, including all of the Columbia River estuary. The ecoregional assessment also ranked the sites according to their relative contribution to biodiversity and their relative vulnerability (Figure 2).

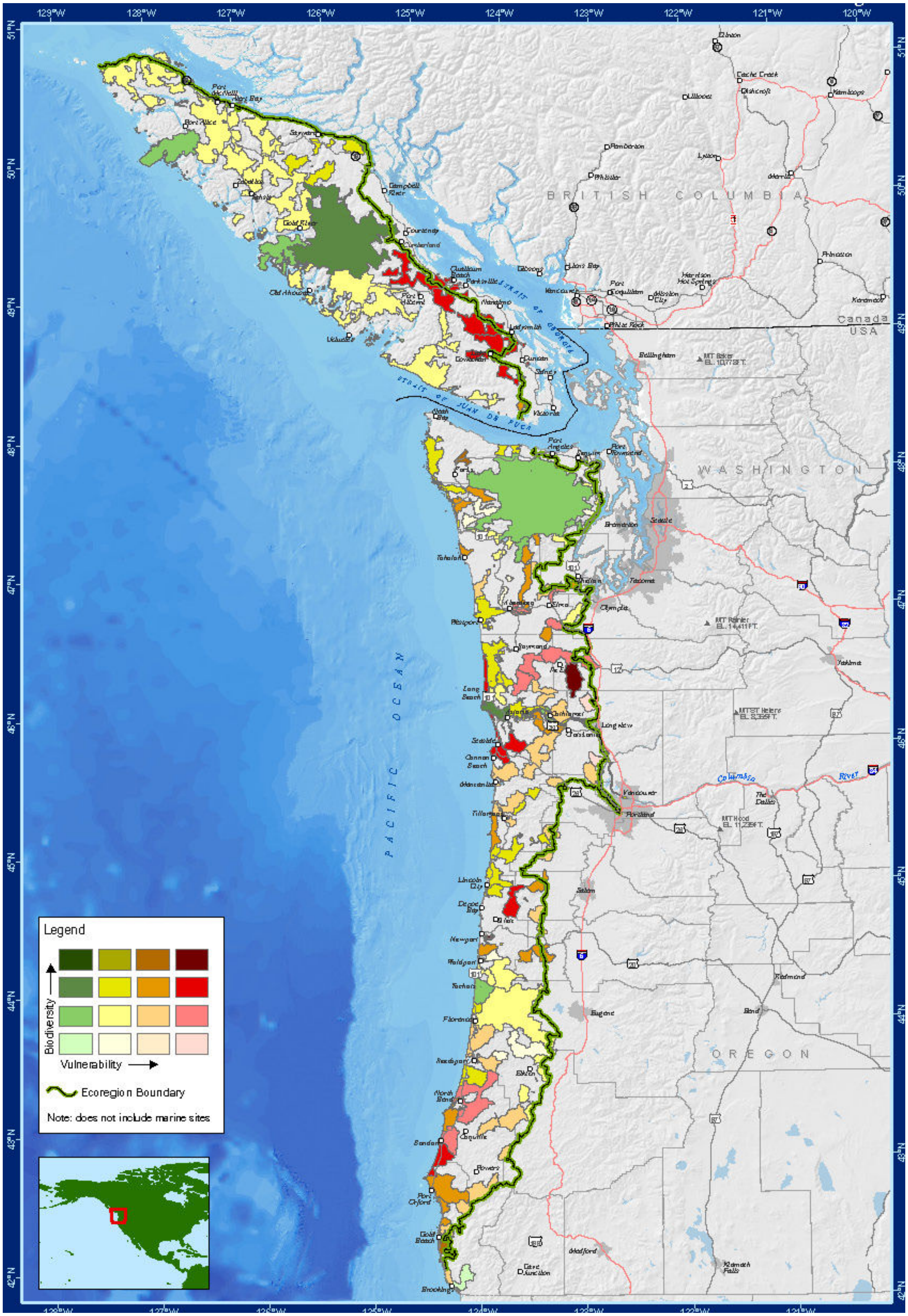


Figure 2. Prioritization of portfolio sites (Vander Schaaf et al. 2007)

In Oregon, estuarine sites tend to have medium-high biodiversity value, and also medium-high vulnerability, in comparison to the rest of the ecoregion.

2. Geographic Scope

Oregon coastal estuaries are found within three Ecological Drainage Units (EDUs). The Oregon Coastal EDU along the entire coast of Oregon includes mid-elevation, predominantly unglaciated mountains progressing to coastal lowlands. There is high rainfall (up to 635 cm/yr). Streams draining the coast mountains are small to medium, deeply incised, steep, and dendritic. Some are small tributary and headwater watersheds of less than 100 km^2, which are distributed fairly densely across the landscape. There are occasional small lakes. Many of these systems are coastal watersheds whose streams flow directly into saltwater or estuaries (Vander Schaaf et al. 2006). The predominant geology is sedimentary and basalt (Vander Schaaf et al. 2006).

The other two EDUs are the Lower Rogue and Umpqua Rivers and the Lower Klamath River which are found in the southern half of the state. These EDUs includes the Klamath mountains with highly variable geology, progressing to coastal lowlands. Annual precipitation is not as high (~100-300 cm/yr). Streams are rapidly flowing through the bedrock in controlled channels to moderately sized rivers. There are numerous glacial lakes above 5000 feet (Vander Schaaf et al. 2006).

In this assessment, we focused on Oregon coastal estuaries, from the Necanicum in the north to the Pistol in the south. Although the Columbia River estuary is one of the larger estuaries on the west coast and provides significant habitat for salmon and other estuarine-dependent species, we excluded it for four reasons. First, it differs significantly in scale and function to the smaller coastal estuaries, and therefore we assumed would differ in the scope and scale of ecological attributes and indicators. Second, several conservation organizations (e.g., Lower Columbia River Estuary Partnership) and research efforts (e.g., Center for Coastal and Land-Margin Research at OGI's School of Science and Engineering) focus on the Columbia River estuary, whereas fewer resources are allocated to the smaller coastal estuaries which also have salmon and other biodiversity resources. Third, most of the Columbia watershed lies outside of the Pacific Northwest Coast ecoregion, and the hydrologic regime is driven by snowmelt, as opposed to the winter rain-driven hydrologic regime of the coastal estuaries . Fourth, the kinds of conservation strategies that would be effective for the Columbia estuary are likely to be quite different from the smaller coastal estuaries. However, we believe the same planning products might be useful to similar conservation efforts for coastal estuaries in Washington (e.g., Hoh River, Quillayute River, Sooes River, and Waatch River) as well as some of the smaller Columbia River sub-estuaries (e.g., Youngs Bay, John Day River, Baker Bay (Chinook River and Wallacut River)) and Grays Bay (Grays River and Deep River).

For this assessment, we included all estuaries (aside from the Columbia) which were identified in the ecoregional assessment for Oregon (Table 1), regardless of how they were ranked in the ecoregional assessment. We define estuaries as "deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, with ocean water at least occasionally diluted by freshwater runoff from the land" (Vander Schaaf et al. 2006). We consider the boundaries of the estuary as extending from the mouth (or the tips of the jetties) to the head of tide, to be consistent with state and federal regulatory authorities and other conservation efforts (Schlesinger 1997; ODLCD 1987). We considered all habitat types that receive some tidal input. This includes habitats that formerly had tidal influence and currently are disconnected from the tide, but are restorable with a reasonable amount of effort, such as former tidal wetlands that are disconnected by levies or tidegates.

Table 1. Characteristics of Major Oregon Estuaries. For descriptions of estuary types, see section below on estuary classification. Oregon conservation classes are designated by the Oregon Department of Land Conservation and Development.

Estuary	Estuary area (ha)	Type (Lee et al. in press)	Oregon Conservation Class	Salmonid use
Necanicum River	138	Tidal dominated drowned river mouth? (bar built)	Conservation	
Ecola Creek	7.7	Tidally restricted coastal creek	Conservation	coho, fall chinook, chum, coastal cutthroat, winter steelhead (Parker et al., 2001)
Nehalem River	1010.6	Tidal dominated drowned river mouth	Shallow draft development	chum, coho, chinook (PSU,1999)
Tillamook Bay	3729.2	Tidal dominated drowned river mouth	Shallow draft development	chinook, coho, chum, cutthroat, steelhead (Ellis, 2002)
Netarts Bay	1035	Bar built	Conservation	chum, coho, winter steelhead (ODFW)
Sand Lake	452.7	Bar built	Natural	chum, coho, winter steelhead (ODFW)
Nestucca Bay	477.6	Tidal dominated drowned river mouth	Conservation	chum, coho, winter steelhead (ODFW)
Neskowin Creek	1.3	Tidally restricted coastal creek	Conservation	
Salmon River	201.7	Bar built? (river dominated bar built?)	Natural	
Siletz Bay	748	Tidal dominated drowned river mouth	Conservation	chum, coho, winter steelhead, coastal cutthroat (ODFW)
Depoe Bay	3.8	Marine harbor/cove	Shallow draft development	
Yaquina Bay	1882.6	Tidal dominated drowned river mouth	Deep draft development	chum, coho, winter steelhead (ODFW)
Beaver Creek	54.6	Tidally restricted coastal creek	Conservation	coho, winter steelhead, coastal cutthroat (ODFW)
Alsea River	1248.8	Tidal dominated drowned river	Conservation	chum, coho, winter steelhead (ODFW)

		mouth		
Big Creek (Lincoln County)	8.8	Tidally restricted coastal creek	Natural	
Yachats River	11.3	Tidally restricted coastal creek? (tidal coastal creek)	Conservation	chinook, coho, steelhead, cutthroat (City of Yachats)
Tenmile Creek (Lane County)	4.2	Tidally restricted coastal creek	Natural	chinook, coho, steelhead, cutthroat (TPL website)
Berry Creek	2.3	Tidally restricted coastal creek	Natural	
Sutton River	14.6	Tidally restricted coastal creek	Natural	coho, winter steelhead (ODFW)
Siuslaw River	1559.1	Tidal dominated drowned river mouth	Shallow draft development	chum, coho, winter steelhead (ODFW)
Siltcoos River	36.4	Tidally restricted coastal creek	Natural	
Tahkenitch	26	Tidally restricted coastal creek	Natural	
Umpqua River	3378.5	River dominate drowned river mouth	Shallow draft development	coho, summer steelhead, winter steelhead (ODFW)
Tenmile Creek (Coos County)	50.3	Tidally restricted coastal creek	Natural	
Coos Bay	5490.4	Tidal dominated drowned river mouth	Deep draft development	coho, winter steelhead (ODFW)
Coquille River	689.4	Tidal dominated drowned river mouth? (river dominated drowned river mouth)	Shallow draft development	chinook, coho, steelhead, cutthroat (ORJV, 1994); ODFW doesn't include chinook or cutthroat
Two mile Ck	10.7	Tidally restricted coastal creek (river dominated drowned river mouth)	Natural	

New River	166.2	Blind	Natural	fall chinook, coho, winter steelhead (ODFW)
Sixes River	32.5	Blind	Natural	
Elk	31.5	Blind	Natural	
Euchre Creek	10.6	Tidally restricted coastal creek	Natural	
Rogue River	326.6	River dominate drowned river mouth	Shallow draft development	fall chinook, summer steelhead, winter steelhead (ODFW)
Hunter	6.6	Tidally restricted coastal creek	Natural	chinook, coho, steelhead (currywatersheds.org)
Pistol River	20.4	Blind	Natural	fall chinook, winter steelhead (ODFW)
Chetco River	85.8	River dominate drowned river mouth	Shallow draft development	fall chinook, winter steelhead (ODFW)
Winchuck River	10.4	Blind	Conservation	coho, fall chinook, winter steelhead (ODFW)

Estuaries differ in their geomorphology, characteristic species and communities, amount of tidal and wind energy, substrates, and other factors. There have been a number of efforts in Oregon and the Pacific Northwest to group estuaries according to different classification systems. For the purposes of this project, we used a classification scheme that groups estuaries into four categories according to distinctions in geomorphology and the relative importance of marine and watershed inputs: bar-built, drowned river mouth, tidally restricted creeks, and blind (Lee et al. in press). We also used a scheme that subdivides the estuaries into four regions – marine, bay, slough, and riverine – in which different species and communities occur and dominant physical processes are either different or behave differently (Figure 3) (ODLCD 1987). Not all regions are present in each estuary type.

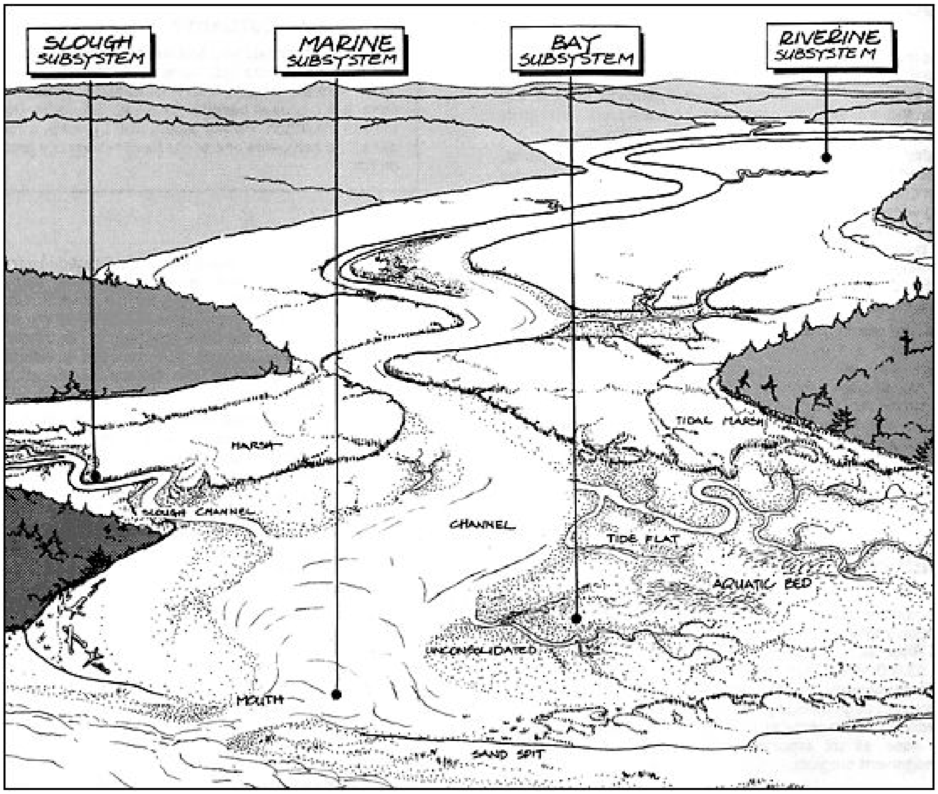


Figure 3. Illustration of estuary regions, from Oregon Department of Land Conservation and Development (1987).

3. *Conservation Action Plan*

The next stage in conservation planning is to focus more closely on particular sites within the ecoregional portfolio with the ultimate goal of identifying conservation strategies to protect and restore the characteristic species and ecosystems. This process is called Conservation Action Planning (CAP) (TNC 2007).

A conservation plan provides a rigorous framework for identifying appropriate conservation strategies that are linked to clearly identified objectives, as well as a means of outlining a plan for monitoring strategy effectiveness and completing the adaptive management loop. The initial planning phase includes three key steps: (1) identify the subset of biodiversity of interest from the larger list of ecosystems and species identified in the ecoregional assessment, (2) construct conceptual ecological models of that biodiversity to organize, document, and communicate information about its viability, (3) determine ways to measure the current viability, or ecological health, and to describe a future viable state. To complete step (1), planning teams identify 10 or fewer ecosystems or species from the ecoregional list that are either keystone species, ecosystems that provide habitat for a broad range of species, or ecosystems that are particularly critical to the biodiversity of the ecoregion. To complete steps (2) and (3), conservation planners use their understanding of the species' or ecosystems' biologies and distributions to select critical ecological attributes that, if missing or altered, would lead to their loss over time. These are called Key Ecological Attributes or simply "attributes". They either can be measured directly, or are measured using a more quantitative indicator. Some examples of attributes for an ecosystem include appropriate hydrologic regime or abundance of a keystone species; examples for a species might include reproductive output or availability of prey. For a more thorough treatment of Conservation Action Planning methodology, see TNC's Conservation Action Planning: Developing Strategies, Taking Action, and Measuring Success at Any Scale (TNC 2007).

The primary goal of this project is to facilitate the planning process at estuarine sites in Oregon by providing preliminary versions of each of the products needed to determine the ecological attributes necessary for the sustained ecological integrity of the species and ecosystems of interest. As we described in the introduction, this assessment was done at an intermediate scale for a subset of estuaries in Oregon that also are found within the ecoregion. They were grouped together because they share species assemblages and ecosystem characteristics, are located within similar landscapes, and face similar threats. The goal of this intermediate step is to make future planning at any one site more efficient.

a. Focal Ecosystem

For this assessment we focused on 'estuarine ecosystems' so that this information could more easily be integrated into conservation plans for coastal areas in which additional freshwater, terrestrial, and marine ecosystems and species also would be included. We chose estuarine ecosystems rather than estuarine habitats or specific estuarine-dependent species in order to cover all of the species and habitats – algae, plant, invertebrate, vertebrate – that rely on estuaries for their survival. However, specific estuarine habitats are highlighted in one attribute, and estuarine-dependent salmon are discussed in greater depth at the end of this report.

b. Conceptual Ecological Models

We can never completely understand all of the factors that influence an ecosystem or a species, but conceptual models help to describe our current understanding of the dominant components and key processes. They can be as simple as box and arrow diagrams, or as complicated as mathematical simulations. For this assessment, we constructed simple box and arrow diagrams for each attribute of the estuarine ecosystems target.

c. Key Ecological Attributes and Indicators

We developed a master list of attributes and indicators for Oregon estuaries. The attributes on the master list vary in their relevance to different types of estuaries and different regions within estuaries, as described above in the section on estuary classification. Thus we also indicated to which estuary types and to which regions the attributes and indicators apply.

We based the development of the conceptual models and the identification of attributes and indicators on information in the ecoregional assessment, conservation plans for estuaries in other states and countries, the published and grey literature, and expert opinion. Our goal was to build upon and incorporate as much as possible existing indicators already being monitored and measured in Oregon.

We selected indicators based on the following criteria:

- Biologically relevant – a meaningful measure of the attribute in question
- Socially relevant – meaningful to various stakeholders (both scientific and lay)
- Measurable – easily quantified with widely available instruments or hardware/software
- Appropriately precise – precise enough to measure ecologically meaningful trends in the attribute in question, yet not so precise as to complicate interpretation of meaningful trends
- Anticipatory – measures a detectable trend or change in a parameter before the attribute has been altered beyond repair
- Cost-effective – reflects the need for some monitoring by stakeholders without large monitoring budgets.

RESULTS

We identified four key ecological attributes for estuarine ecosystems (Table 2). Each of these attributes is applied to every type of estuary in Oregon, however, the indicators, and the ways they are measured, vary by estuary type and by region of the estuary. Each attribute is discussed individually in the following sections.

Table 2. Master list of attributes and indicators selected. Also included are the estuary type where each attribute/indicator combination is relevant, and the region in the estuary where it should be applied. These attributes and indicators are described in more detail in subsequent sections. M=Marine; B=Bay; S=Slough; R=Riverine.

Attribute	**Indicator(s)**	**Estuary type**	**Estuary region**
Hydrology / circulation	Freshwater inflow	All except bar-built	R
	Tidal inflow	All	All
	Estuary surface area	All	All
	Estuary depth	All	M, B, S
Sedimentation	Watershed: • Surface erosion • Mass wasting • Sediment delivery to estuary	All except bar-built	R
	Within estuary deposition	Addressed in hydrology/circulation KEA	
	Coastal inputs: • Bluff erosion • Beach & dune erosion / deposition • Littoral drift	All estuaries with a bar (and those with erodible bluffs in drift cells for bluff erosion)	M, B

Habitat extent and distribution	Hydrologic connectivity	All	Tidal marshes (MA), tidal channels (TC), tidal swamps (TS)
	Composition	All	All habitats
	Extent	All	All habitats
Water and sediment quality	Watershed nutrient inputs	Blind and tidally-restricted coastal creeks	All
		bar-built	M, B, S
		river-dominated drowned river mouth	All
		tide-dominated drowned river mouth	B, S, R
	Watershed toxin inputs – amphipod analyses	All	All
	Watershed toxin inputs –direct measures	All	All

1. *Estuarine Circulation:*

a. Ecological role

Waters that feed an estuary are either salt water (oceanic in origin) or freshwater (riverine in origin), making estuaries intermediate in salinity between these two sources. Spatial gradients in salinity arise across the estuary when the fresh and salt water enter at distinct locations and mix in different ways. Freshwater is less dense than salt water, and so riverine water floats on oceanic water, creating vertical salinity gradients.

In addition to the relative volumes of oceanic versus riverine inputs, salinity gradients are developed and maintained by three mixing or circulation processes within an estuary (Hickey and Banas, 2003):

- Wind – Waves produced from wind, particularly in shallow estuaries, mix waters throughout the estuary.
- Tidal action – Tidal currents play an important role in mixing oceanic and freshwater to produce estuarine salinity gradients.
- Density-driven mixing – In deeper estuaries, the vertical stratification described above produces a density gradient that itself creates a mixing force. Turbulence along the gradient from saline to freshwater causes the two water lenses to start to mix, at which point the salt

water becomes less dense and rises, which creates a water current that further increases mixing (Hickey and Banas, 2003).

Estuarine circulation and the resulting salinity gradients, as well as water movement and sediment deposition are central to the distribution of biological communities, habitats, and ecological processes (Gaiser et al. 2005; Bottom et al. 2005; Day et al. 1989; Jassby et al. 1995; Bottom et al. 1979). For example, the distribution of benthic organisms is structured primarily by salinity gradients and substrate type (Emmett et al., 2000). The distribution and productivity of fish communities in west coast estuaries is governed by salinity, temperature, and the location of the turbidity maximum, all of which are factors regulated in large part by estuarine circulation (Emmett et al. 2000; Simenstad 1983; Jassby et al. 1995).

Similarly, the distribution of estuarine habitats is maintained in part by salinity and hydrologic gradients. The structure and extent of tidal channels are a product of the volume of tidal water moving adjacent to intertidal and supratidal habitats (Hood 2004). In Washington, Hood (2004) found that reducing the extent of tidal currents can produce changes in the tidal prism (the volume of tidal water entering the estuary), which resulted in a loss of tidal channel sinuosity and other structural changes. In the Washington example, habitat loss occurred on the tide-side of dikes, not only in the area with no tidal access, and is believed to result from reduced tidal inputs.

The locations of high and low salt marsh arise from salinity gradients and inundation patterns (Day et al. 1989; Luternauer et al. 1995). The volume of freshwater entering an estuary negatively affects the distance upstream that salt water can move into a watershed and the salinity gradient within the estuary (Jassby et al. 1995; Hickey and Banas 2003). This balance structures the distribution of freshwater tidal wetlands and salt marshes.

Seasonal differences in the relative volumes of water from marine and riverine sources lead to differences in sediment deposition (Peterson et al. 1984). When riverine inflow outweighs tidal inflow (usually during winter), sand and other sediments are moved through the estuary and out toward the ocean. When tidal inputs are large relative to freshwater inputs (usually during summer on the west coast), sediment particles will be trapped in the basin rather than flushed out of the estuary.

b. Differences among estuary types

The factors governing the circulation and mixing of fresh and salt waters vary by estuary type and by estuarine geomorphology. Regardless of estuary type, in shallow parts of estuaries, mixing is largely the product of wind and tide. In deeper areas within estuaries, density-driven mixing processes dominate, at least during the winter when river flows are high (Hickey and Banas 2003). However, freshwater inputs to both drowned river mouth and blind estuaries are extremely variable along the west coast (due to a winter storm season and a summer dry season), so the importance of density-, tide- and wind-driven mixing can vary within a single estuary throughout the year (Hickey and Banas 2003).

Generally, in drowned river mouth estuaries, freshwater inflows are large in the winter season, and they are highly stratified and well flushed with fairly short residence times (Simenstad 1983). In the summer, as freshwater inflows decrease relative to marine inputs, these estuaries become well-mixed, largely due to tidal action.

These same patterns generally hold true for blind estuaries in which the bar across the estuary mouth is breached during the winter. If the bar is not breached (i.e. if freshwater flows are not large enough to erode the sand bar), then the estuary has lower salinity and can verge upon being freshwater. During the low flow conditions in summer, these estuaries are usually isolated from marine waters and freshwater dominates. Mixing, if it occurs, is usually due to wind action in the bay during the summer.

In bar-built estuaries with very little freshwater inflow, the seasonal patterns of stratification and mixing are not as prevalent. Marine waters maintain most of the inundation within the estuary.

In tidally restricted coastal creeks, the connectivity between the ocean and the river declines dramatically during the summer low flow season. As a result, the circulation patterns of these estuaries are somewhat similar to blind estuaries.

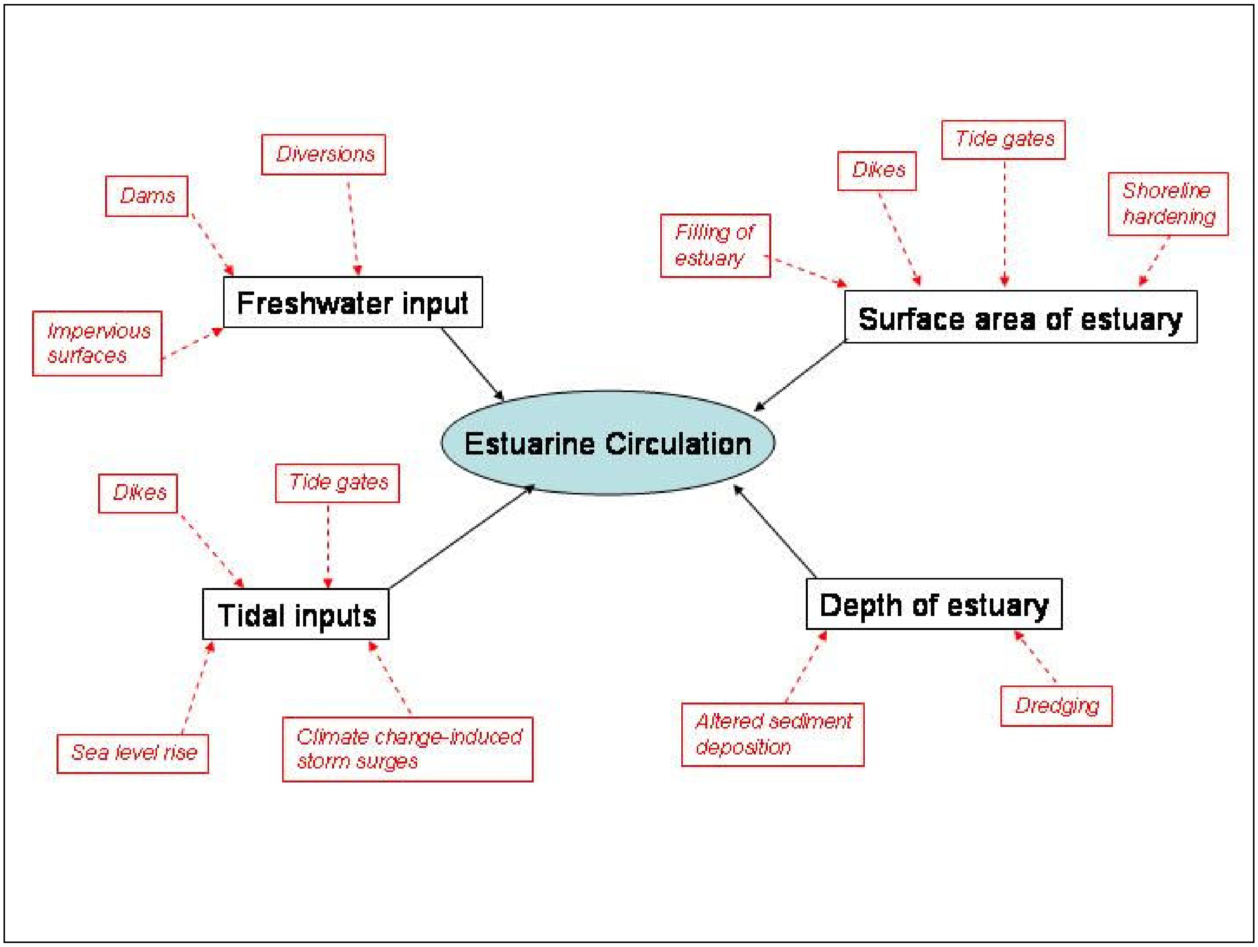


Figure 4: Conceptual ecological model of estuarine circulation. Indicators are in black boxes; threats to the functioning or condition of these attributes are shown in red italics.

c. Proposed Indicators

Water circulation in an estuary is a function of four factors (Komar, 1997): (1) volume of freshwater flow from rivers, (2) volume of tidal currents flow, (3) estuary surface area, and (4) estuary depth. These are listed in Table 3 and described below.

Table 3: Indicators of estuarine circulation attribute. Relevant estuary types and the region of the estuary where the measurement should be made also are included. Measurements are proposed for each indicator. M=Marine; B=Bay; S=Slough; R=Riverine.

Attribute	Indicator	Estuary type	Estuary Region	Measurement
Estuarine circulation	Freshwater inflow	All except bar-built	R	Presence of dams Presence of major diversions Percentage of watershed in impervious surface (Trends in the magnitude and timing of peak flows)
	Tidal inflow	All	All	Percent of historic tidal wetlands that are disconnected from tides
	Estuary surface area	All	All	Percent of estuarine area that has disrupted hydrologic connectivity (including tidal, riverine, and estuarine inputs)
	Estuary depth	All	M, B, S	Absence of dredging

Freshwater inflow: Most estuaries in Oregon do not have long-term streamflow records, so we suggest this indicator be evaluated by the absence of activities within the watershed that are known to affect the magnitude and timing of streamflows:

- *Presence of dams and diversions*: If there are neither dams nor diversions in the watershed, it is likely that the volume of freshwater flow entering the estuary has not been reduced. If there are dams or diversions in the watershed, then further analysis of flow regimes will be needed to identify the effects that these activities are having on river flow to the estuary and to determine whether a minimum estuarine river flow is needed. This more detailed analysis may be needed in some of the larger estuaries where river inputs may be lower than would be expected naturally due to appropriated water withdrawals in the watershed (Good 2000).

- *Percentage of watershed in impervious surfaces*: Impervious surfaces in a watershed, particularly on permeable geologic deposits, can increase surface water runoff during peak flow as well as change the timing of surface flows (Booth et al. 2002). Recent work in the Pacific Northwest indicates that these changes in runoff cause ecological and physical damage to streams and estuaries when more than 7.5-10% of the watershed is covered by impervious surfaces (Booth et al. 2002; Sutter 2001). An analysis by Lee et al. (in press) of the Oregon coast watersheds indicates that none of the estuaries being evaluated are in watersheds that exceed the threshold of 10%.

- *Trends in the magnitude and timing of peak flows*: Estuaries with appropriate streamflow data for the lower watershed can be evaluated for changes in the magnitude and timing of peak flows (Good 2000). However, these types of data should be used with caution and the following caveats should be mentioned:
    - Trends in hydrographs do not anticipate threats to streamflow because the measured response often appears after the changes have occurred.
    - It can be difficult to interpret the meaning of trends and identify the root causes of the change. This makes identifying appropriate conservation strategies more complicated.
    - On the Oregon coast, annual flow patterns are variable because they depend upon climatic conditions during the winter. This makes identifying thresholds and a meaningful desired future condition difficult.

Tidal inflow: The amount of tidal water entering an estuary is a function of tidal ranges and sea level. Because these factors are not within the control of local managers, we do not propose them as indicators. Furthermore, measurements to track climate change impacts to estuaries such as sea level rise or an increase in tidal currents from storm surges are beyond the scope of this project.

The volume of tidal water that can reach estuarine habitats is governed by the morphology of the estuary, including its depth (discussed below) and the extent of tidal habitats (Komar, 1997). Rather than directly measuring the area inundated by tidal waters, we propose to measure the *percentage of estuarine habitats (including historic tidal wetlands) currently disconnected from tides*. Thus we assume that the indicator of tidal inputs is functioning adequately if there are few or no estuarine habitats separated from the main estuary by levees or other barriers. This is the approach taken by the State of the Environment Report in Oregon (Good 2000). For major estuaries, a coarse assessment was done by estimating the loss of estuarine area, including filling as well as disrupted hydrologic connectivity, based on a 1970's assessment of estuary extent (Good 2000). Other resources such as watershed analyses may be helpful for completing this initial assessment (e.g., Brophy 2005).

An assessment of the percent of disconnected habitats is needed to prioritize estuaries for restoration and to monitor the effectiveness of conservation strategies within an individual estuary. A first step is to map the locations of all structures that restrict tidal access to estuarine habitats, including tide gates, dikes, causeways, and riprap or other structures that harden shorelines and prevent habitat flooding. The greater the proportion of tidally connected habitat, the more intact the estuary's ecology. However, it is difficult to set thresholds beyond which the estuary's integrity is threatened. Instead, we recommend that users determine the current extent and set the desired future condition as a certain percent decline in these structures over a specified period of time.

Estuary surface area: The surface area of the estuary includes all habitats that should be connected hydrologically to either fresh or saline waters. The proposed measure of this indicator is the same as that for tidal inflow, *percentage of historic estuarine area currently disconnected from tides*.

Estuary depth: The depth of the estuary determines to a large extent the shape of the tidal prism and the mixing of saline and fresh waters. Increased sediment deposition makes the estuary more shallow and can create a less stratified, more mixed estuary. Conversely, deepening an estuary, for example by dredging, can impair mixing and produce a more stratified estuary. Proposed measures of altered sediment supply are in the sedimentation discussion (attribute #2); here we focus on increased estuary depth via dredging.

Whether an estuary is dredged or not is a good first approximation to evaluate if mixing processes have been changed by estuary deepening. To determine the specific impacts and set depth thresholds beyond which mixing is impaired, it may be necessary to study estuarine circulation patterns in more detail, including the use of circulation models.

2. Sedimentation

a. Ecological Role

The spatial distribution of different sized sediment particles plays a role in controlling the distribution and function of biological communities, such as benthic fauna, fish, and vegetation, and the distribution of contaminants within an estuary (Bottom et al. 1979; Dyer 1995; Emmett et al. 2000). Plant establishment, invertebrate adaptations for burrowing, attachment, and feeding, and the distribution of feeding and nesting habitat for fish and other mobile species also are related to substrate types (Bottom et al. 1979).

Sediment deposition and erosion act in conjunction with estuarine circulation to structure estuary morphology, which in turn determine the locations of specific habitats. For instance, sea grass colonization depends in part on appropriate water depth and clarity (Phillips 1984; Mumford 2007), which are a function of sediment deposition and movement. Emergent or submerged vegetation tends to colonize fine-grained sediments where nutrient availability is higher (Day et al. 1989). Sediment size determines the availability of different food sources for salmon. For example, chum favor mudflats whereas Chinook salmon use sand flats (Simenstad et al. 1991).

Sediment supply and deposition creates the bar/spit formations across the mouths of some estuaries. Bar size can determine connectivity with the ocean and thus the salinity gradient and estuarine circulation (Army Corps of Engineers 1995; Hubertz et al. 2005)

b. Differences among estuary types:

Sediment regime is important for all estuaries, but it differs among estuary types. All estuaries with freshwater inputs depend upon sedimentation of both watershed and marine sediments, although the relative volume and distribution of each varies by season in response to variations in freshwater inflows. The sediment inputs of bar-built estuaries, which receive little freshwater, relies on marine sources. The formation and maintenance of a bar or spit across the mouth of an estuary depends on coastal or near-shore sediment movement and deposition.

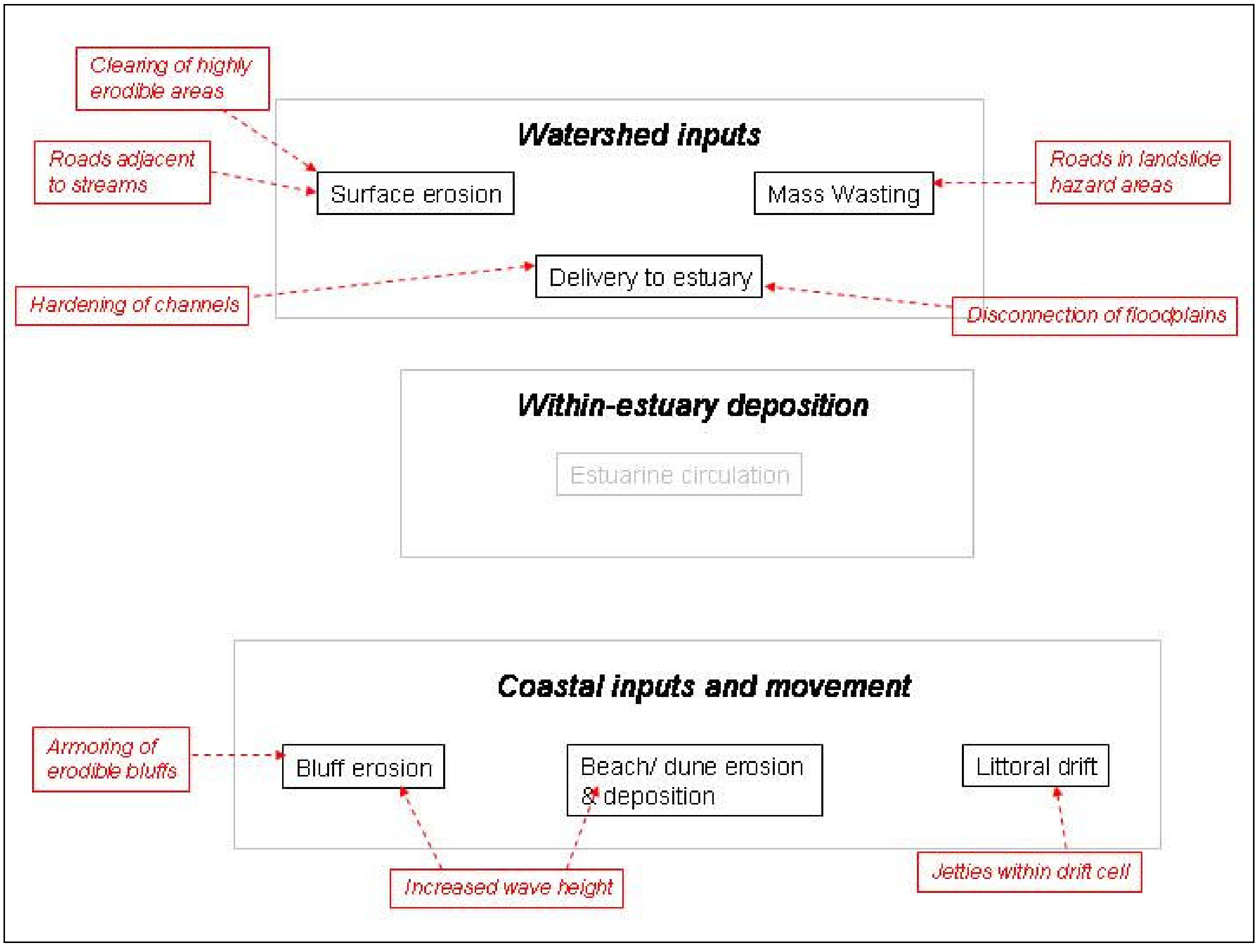


Figure 5: Conceptual model of sedimentation in estuaries. Indicators are shown in black boxes; threats to the functioning or condition of these attributes are shown in red italics. Within-estuary deposition is addressed in the estuarine circulation section (attribute #1) of this document, hence it is in light gray.

c. Proposed Indicators:

Estuarine sedimentation includes three elements (Figure 5; Table 4): watershed inputs, deposition in the estuary, and coastal inputs and movement that create and maintain bars (when bars are present).

Table 4: Indicators of sedimentation attribute. Relevant estuary types and the region of the estuary where the measurement should be made also are included. Measurements are proposed for each indicator. M=Marine; B=Bay; S=Slough; R=Riverine.

Attribute	Indicator	Estuary type	Estuary region	Measurement
Sedimentation: Watershed inputs	Watershed surface erosion	All except bar-built	R	Percentage of areas in watershed that have been cleared and are at risk for increased surface erosion. Higher risk areas are defined as those with: slope >65% slope 30-65% + K factor >0.25 slope <30% + K factor >0.4
				Kilometers of river with roads within 61m (200 feet)
	Watershed mass wasting	All except bar-built	R	Percentage of landslide hazard areas in watershed with roads
	Sediment delivery to estuary	All except bar-built	R	Kilometers of river hardened or disconnected from floodplain
Sedimentation: Estuarine deposition	Addressed in the estuarine circulation KEA discussion			
Sedimentation: Coastal inputs	Bluff erosion	All estuaries with a bar with erodible bluffs in drift cell	M,B	Absence of armoring on erodible shoreline bluffs
	Beach & dune erosion/ deposition	All estuaries with a bar	M,B	Absence of invasive beach grasses
	Littoral drift	All estuaries with a bar	M,B	Percentage of shoreline hardened in relevant littoral cell

Watershed Input: Estuarine sedimentation rates are temporally and spatially variable, and studies indicate that it is difficult to link that variation to unnatural perturbations of the ecosystem (McManus et al. 1998). Therefore, we do not recommend establishing desired future conditions for sediment inputs. Rather, we suggest using the absence of activities or conditions known to increase sediment inputs to estuaries as an indicator that this component of the sedimentation attribute is relatively unaltered. Currently the state of Oregon (DEQ) is considering shifting the assessment of impaired waters for sediment from turbidity measurements to the use of the Relative Bed Stability protocol being developed by the EPA as part of its Environmental Monitoring and Assessment Protocol (EMAP). This approach has been tested in the Nestucca watershed and currently is being tested in the Tillamook Basin. If it proves successful, it may serve as a more direct indicator of sedimentation concerns within a watershed than the approach proposed below.

There are two primary watershed sediment sources to estuaries (excluding in-channel erosion): surface erosion and mass wasting (or landslides).

Surface erosion: Surface erosion moves soil particles to streams where they can be transported downstream to the estuary. The potential for surface erosion is a function of soil erodibility, slope, and vegetative cover (Washington Forest Practices Board (WFPB) 1997). The inherent erodibility of different soil types is described by their K factor (a higher value indicates greater propensity for erosion); this is available from NRCS soil surveys. The risk of soil erosion is highest on highly erodible soils on steep slopes that have been cleared of vegetation. The measurement for this indicator is the *percentage of areas in the watershed that have been cleared and are at risk for increased surface erosion*, with high risk areas defined by a combination of slope and soil K factor (Table 4).

Roads adjacent to water bodies also can increase sediment delivery to rivers. In general, the negative effects of roads depend upon their construction and condition; however, most agencies have established a distance from rivers, lakes, and wetlands within which roads are considered likely to increase sediment delivery to aquatic resources. While the ODOF uses 15 m (50 feet) as the distance within which roads pose a risk of increased sediment delivery to aquatic resources; however, to be more protective, we suggest using the standards established by the Washington Forest Practices Board (WFPB 1997) of 61 m (200 feet). As a result, the measurement for this indicator is the *kilometers of river with roads within 61 m.*

Mass wasting: The establishment of roads on areas prone to mass wasting or landslides can increase the likelihood that a landslide will occur, potentially delivering sediment to adjacent streams. No comprehensive datalayer exists of landslide potential along the Oregon Coast Range; however, Dan Miller has developed software, used by the US Forest Service, that can be used to map areas with natural landslide susceptibility. If this software is run for the watershed of a particular estuary, a GIS analysis can be completed to identify landslide-prone areas intersected by roads or recently cleared vegetation. While this analysis is not yet complete, the methods are described in Miller (2006) and the software is available from Dan Miller (danmiller@earthsystems.net). After the model has been run for the appropriate estuary watershed, the measurement for this indicator is the *percentage of landslide susceptible areas intersected by roads.*

Sediment delivery to estuary: An estuary also can receive unnatural amounts of sediment if alterations, such as bank hardening or diking, higher up in the watershed prevent the deposition of sediments on the river floodplain. To measure the extent of this threat, we propose the indicator of *kilometers of river hardened or disconnected from the floodplain*.

Estuarine Deposition: On the Oregon coast, sediment deposited in the estuary is from a combination of riverine and coastal sources (Peterson et al. 1984). The relative amounts of these two sources is a function of estuarine circulation patterns (Komar 1997) which were addressed above under attribute #1, Estuarine Circulation.

Coastal inputs: Coastal sediments are largely responsible for creating bars across the mouths of certain estuaries. Some of this material also travels into the estuary where it is deposited (Peterson et al. 1984). The supply of coastal sediments originates from five sources: coastal bluffs, beach sands and dunes, littoral drift, rivers, and beach sands. We do not include the latter two in this discussion for the following reasons. The contribution of riverine inputs to coastal sediments is thought to be minor for Oregon estuaries because most riverine sediment gets deposited in the estuary (Peterson et al. 1984; Jonathan Allan, ODGAMI, personal communication). So this sediment source is not included in the remainder of this discussion. Beach sands were deposited 4000 years ago on the continental shelf and moved landward as sea level rose in the past (Jonathan Allan, ODGAMI, personal communication). Even though this may be an important source of sand, threats to this source are unlikely because it is a relict of historic conditions. Therefore, we do not include it in further discussions.

Coastal bluff erosion: Beach bluff erosion can be an important source of beach sands, which contribute to bars and spits across estuary mouths as well as the coastal dune systems. Only bluffs made from material that degrades into sand-sized particles is an important source of this material. Along the Oregon coast, most of the coastal geologic deposits are mudstones and siltstones (Komar and Shih 1993), which erode into particles that are fine and are transported and deposited offshore (Jonathan Allan, personal communication). Only a few areas along the Oregon coast have geologic deposits that erode into sands, and they tend to be fluvial or other deposits laid down upon a basement of finer-grained materials. In these areas, *shoreline hardening* and other activities that restrict bluff erosion threaten this source of coastal sediments (Johannessen and MacLennan 2007).

An initial assessment based on the littoral cells, the statewide geology datalayer (Walker and MacLeod 1993), and information on cliff erosion along the Oregon coast (Komar and Shih 1993) suggests that reduced bluff erosion is a threat in the following estuaries with bars: Sand Lake, Nestucca, Alsea, Two Mile Creek, New river, Sixes, Elk, Pistol and Winchuck.

Erosion of beach sands and dunes: Beach and dune erosion can be a sediment source for estuarine bars and also can control the size and shape of existing bars. Three factors – sediment supply, water levels, and currents – control the rate and location of beach erosion (Jonathan Allan, ODGAMI, personal communication). Other than sediment supply, which is addressed above, water level is the factor most likely to be altered from its natural state. Changes in water level, wave heights, and other factors influencing water levels likely will be associated with climate change but are beyond the scope of this project.

There is evidence that invasive beach plants can alter beach sand processes (Mitchell et al 1994). European beach grass (*Ammophila arenaria)* was planted to stabilize dunes starting in the early twentieth century, with additional planting efforts in the 1930's and 1950's. This changed the shape of foredunes from hummocks to longer, larger dunes (Wiedeman 1984). Thus the indicator for this is the *absence of invasive beach grasses*.

Littoral drift: Coastal sediment moves along the shoreline in drift cells (or littoral cells) through a process known as littoral drift. This section applies only to estuaries with bars or spits at their mouths. Littoral drift is caused by currents and wind along the coast that move beach sediment either north or south and shape estuary mouths and bars (Wiedeman 1984). Along the Oregon coast, beach sand movement occurs between headlands because wave forces generally are not strong enough to move sediment around the headlands (Allan 2005). The area between two adjacent headlands is called a littoral cell. Along the Oregon Coast there are 18 littoral cells (Jonathan Allan, ODGAMI, personal communication) (Figure 7). *Jetties and other structures built in the nearshore zone* are the primary threats to littoral drift, thus this is used as the measure of impaired littoral drift.

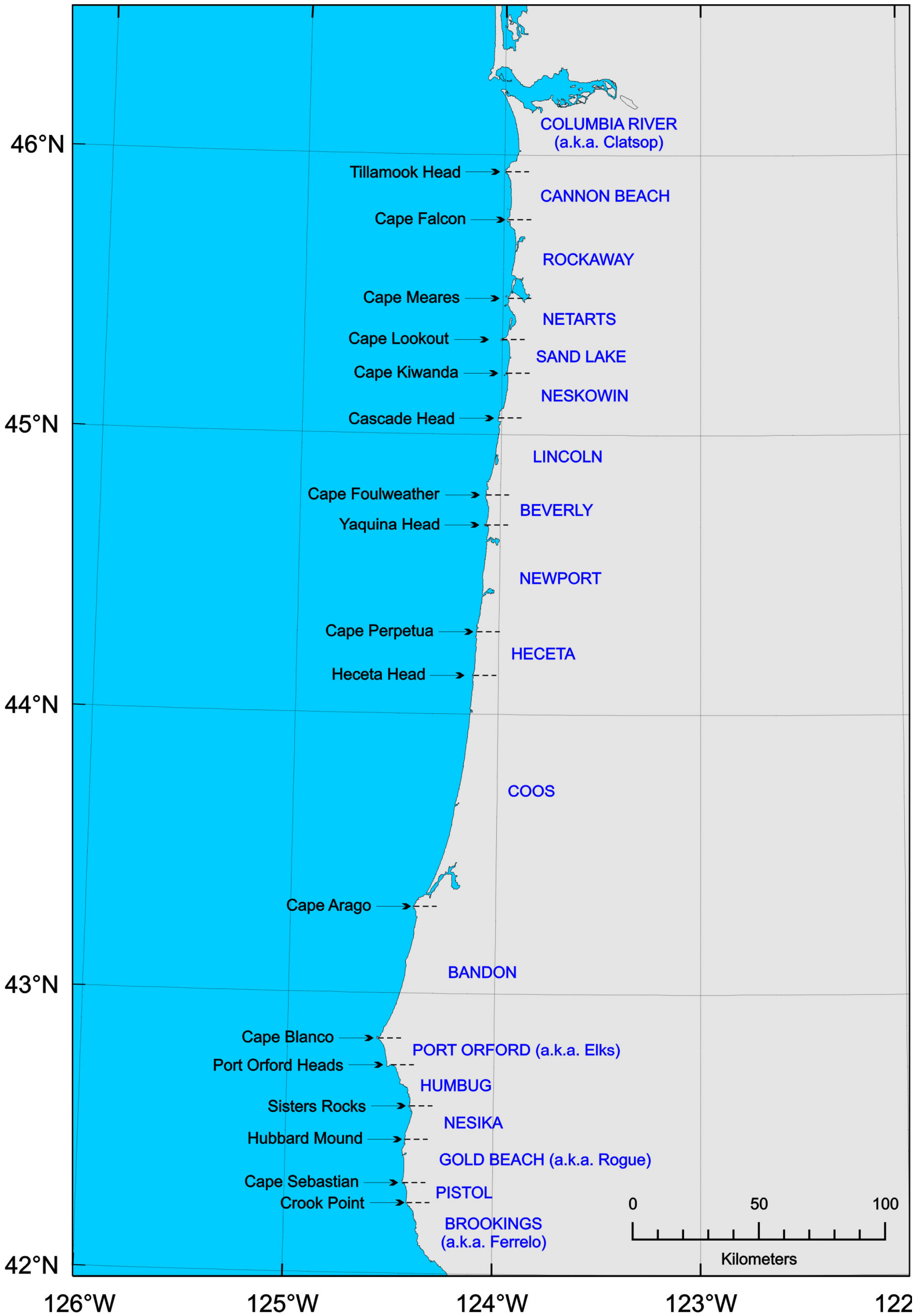


Figure 7: Littoral cells of Oregon coast. Capes or headlands are indicated in black; littoral cell names are shown in blue. Map courtesy of Jonathan Allan, ODGAMI.

3. *Habitats – extent, condition, and distribution.*

a. Ecological Role

Estuaries contain a matrix of habitats that range in tidal position from the subtidal to the supratidal, and include distinct habitats such as mud flats, eelgrass beds, and salt marshes. The elevations of different habitats with respect to tidal waters depend on a dynamic equilibrium among sediment accumulation, coastal subsidence, and sea level rise (Schlesinger 1997). While each of these is important for the plants and animals that live in that habitat, the presence of a connected matrix of habitats is critical because many water-bound species move among habitats for breeding, feeding, and shelter. Furthermore, nutrients and organic particles critical to the entire food web are transferred continually among habitats. This continuous exchange is facilitated by tides and currents, which only function naturally when there are few or no artificial barriers such as levees.

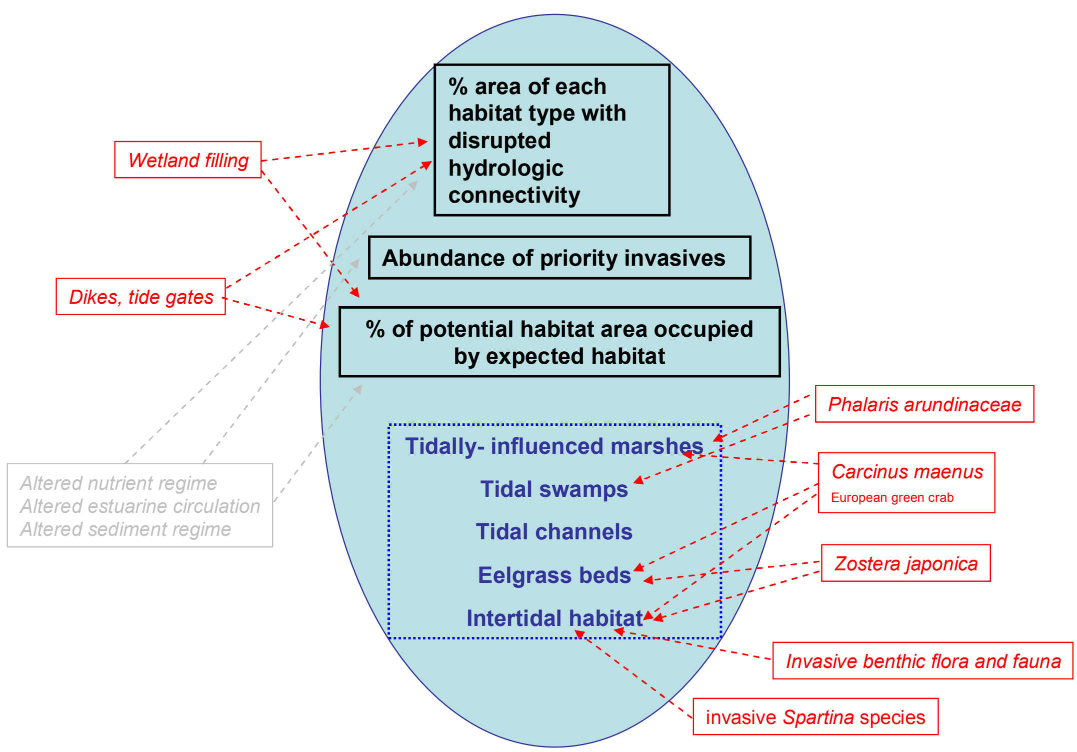
b. Differences among estuary types:

Five habitat types have been identified as particularly important in estuaries (Table 5). For this KEA, we suggest that the presence, extent, and condition of each of these should be evaluated in estuaries where they occur.

Table 5: Key estuarine habitats, the estuary type in which they occur, the regions of the estuary in which they occur, and an explanation for why each was chosen. M=Marine; B=Bay; S=Slough; R=Riverine.

Habitat type (abbreviation)	Estuary type	Estuary regions	Rationale
Eelgrass beds (EB)	Bar built Drowned river mouth	B, S	Nursery and feeding grounds for juvenile salmon (Philips 1984), Pacific herring (Simenstad 1983), and other juvenile fish (Hosack et al. 2006); primary food source for migrating Brants Geese (Phillips 1984); high invertebrate densities support a diversity of shorebirds and ducks (Phillips 1984); habitat for Dungeness crab (Phillips 1984). Eelgrass distribution, abundance, and flowering affected by climatic variation (Thom et al. 2003).
Tidally-influenced marshes (high salt, low salt, freshwater) (MA)	All	B, M, R, S	80% of OR salt marshes converted to agriculture (Frenkel et al., 1981); rearing habitat for salmonids (Miller and Sadro 2003, Bottom et al. 1979) and other fish (Ellis, 2002); feeding and wintering areas for migrating waterbirds (Bottom et al. 1979, Seliskar and Gallagher 1983).
Tidal channels (TC)	All	B, S, R	Provides food sources for salmonids and refuge

			from predators (Bottom et al. 2005, Simenstad, 1983); migratory routes for upstream-bound salmon and other fish; conduits for exchange of water, nutrients, and detritus (Brophy 2007).
Tidal swamps (TS)	All	R, S	Tidal swamps and marshes are the most altered estuarine habitat (68% lost between 1870 and 1970) (Good 2000); rearing habitat for salmonids (Bottom et al. 2005); less than 5% of original extent remaining (Brophy 2007)
Non-vegetated intertidal areas (IT)	All	B, M, S	Supports benthic invertebrates such as clams and ghost shrimp (Bottom et al. 1979); important food sources for bottom feeding fish and shorebirds (Bottom et al. 1979); juvenile salmon occupy intertidal flats (Bottom et al. 2005); important for nutrient fluxes because of bioturbation and filter feeding.



ESTUARINE HABITAT

Figure 8: Conceptual model of estuarine habitats and threats. Key habitats are in the blue dashed box embedded in the light blue oval. Indicators are in black boxes. Threats discussed in the habitat attribute are in red. Threats discussed elsewhere are in gray.

c. Proposed Indicators:

Table 6: Indicators for the estuarine habitat attribute. Habitat types to which the indicators apply also are included. Measurements are proposed for each indicator.

KEA	Indicator	Habitat type	Measurement
Habitat extent and distribution	Hydrologic connectivity	MA, TC, TS	Percent of area of each habitat type subject to disrupted hydrologic connectivity
	Composition	All	Abundance of priority invasives for each habitat type: *Zostera japonica* (IT, EB) *Carcinus maenus* (green crab) (IT, MA, EB) *Nuttallia obscurata* or other invasive benthic species (IT) Invasive *Spartina* species (IT, MA, EB) *Phalaris arundinaceae* (TS, MA)
	Extent	All	% of potential habitat area occupied by expected habitat

Hydrologic connectivity: This indicator is essentially the same as the estuary surface area (in the estuarine circulation KEA) except that the assessment is now conducted for each specific habitat type. The analysis will be helpful for tracking trends in specific habitats and ensuring that a diversity of habitats have good hydrologic connectivity. Some estuaries have habitat data, for example eelgrass beds, marshes, and intertidal habitats were mapped for the Estuaries Plan Book (ODLCD 1987) and the data are available for 17 of the larger estuaries (http://www.inforain.org/mapsatwork/oregonestuary/datasets.htm). Marshes and tidal swamps (mapped as forested wetlands) were mapped for 38 estuaries from Scranton (2004) wetland mapping data
Further information will be necessary from estuaries with no existing data.

Composition: The abundance of priority non-native species is used as a surrogate measure for estuarine habitat condition. We identified five priority estuarine invasive species (Davidson et al. 2007):

- *Zostera japonica* (Japanese seagrass): Displaces native seagrasses; changes sediment and nutrient deposition patterns in intertidal zones (Davidson et al. 2007). Alters water column and benthic nutrient availability in estuary (Larned 2003).
- *Carcinus maenus* (green crab): Inhabits a wide range of intertidal and subtidal habitat, including salt marshes and seagrass beds (Ray 2005) and tolerates a broad range of salinities

and temperatures (Davidson et al. 2007). Predator to numerous native species including molluscs and crustaceans; significantly reduces native clams and crabs; substantial indirect effects on shorebirds and commercial fisheries through consumption of food resources (Grosholz and Ruiz 2002).

- Invasive benthic species: Non-native clams such as *Nuttallia obscurata* (purple varnish clam), *Potamocorbula armurensis* (Asian clam), and *Mya arenaria* (Eastern softshell clam) found in mid to high intertidal zones can spread rapidly and displace native clams (Ray 2005; Boersma et al. 2006). *Mytilus galloprovincialis* (Mediterranean mussel) found in intertidal and subtidal zones also exclude native species (Ray 2005; Boersma et al. 2006).
- Invasive *Spartina* species (cordgrasses): Spreads rapidly and forms dense monocultures in tidal mudflats, salt marshes, and sloughs (Davidson et al. 2007; DiTomaso and Healy 2003). Changes hydrologic regime by elevating mud flats that are normally devoid of vegetation; alters shoreline topography; displaces eelgrass, native salt marsh plants, and invertebrate communities (DiTomaso and Healy 2003).
- *Phalaris arundinaceae* (Reed canarygrass): Forms dense monocultures in freshwater and brackish wetlands that displace native plants and animals (Lyons 1998; DiTomaso and Healy 2003). Development of thick sod layer elevates the wetland surface, altering ecosystem properties such as sedimentation, hydrology, and nutrient cycling (Boersma et al. 2006; Lavergne and Molofsky 2004).

The vulnerability of different estuaries to invasion by these species depends upon whether appropriate habitat exists. Many estuaries have already been invaded by the high priority exotics (Table 7).

Table 7: Estuaries containing appropriate habitat for (gray) and occurrences of (black) priority exotic species. Unlisted estuaries do not have appropriate habitat. Habitat data from Estuaries Plan Book draft portfolio habitat data (ODLCD 1987) and Scranton (2004) wetland mapping data; occurrences for *P. arundinaceae* from Brophy and So (2005a), Brophy and So (2005b), Brophy (2005), and Brophy (1999); all other occurrences from Yamada (2003).

N to S #	Estuary	*Zostera japonica*	*Carcinus maenus*	*Nuttallia obscurata* (invasive benthic species)	Invasive *Spartina* species	*Phalaris arundinaceae*
2	Necanicum					
3	Ecola Creek					
4	Nehalem					
5	Tillamook					
6	Netarts					
7	Sand Lake					
8	Nestucca					
10	Salmon					
11	Siletz					
13	Yaquina					
14	Beaver Creek					
15	Alsea					
22	Siuslaw					
23	Siltcoos					
24	Tahkenitch					
25	Umpqua					
26	Ten Mile Ck South					
27	Coos Bay					
28	Coquille					
29	Two Mile Creek					
31	New River					
32	Sixes					
33	Elk					
34	Euchre Ck					
35	Rogue					
36	Hunter Ck					

37	Pistol River					
38	Chetco					
39	Winchuck River					

Habitat extent: The percent of the expected habitat that exists within a particular estuary is the third indicator for the habitat attribute. A variation of this also was used in the Good (2000) report, where they included two habitats: eelgrass beds and tidal wetlands, the latter of which is a combination of salt marsh and swamp. Predicting where the different habitats are expected to exist will require a map of bathymetry and some decision rules for the expected locations of the different habitats. For instance, native eelgrass beds are generally found lower than 0.5 - 0.7 m above mean low low water (Specht et al. 1999; Larned 2003). However, some caution is necessary when trying to identify the expected locations of eelgrass beds because these tend to be difficult to map (Steve Rumrill, pers. comm.).

For this assessment, we did not include the diversity of habitat types within an estuary as an indicator for the habitat attribute. Many of the smaller estuaries along the Oregon coast naturally only have a smaller subset of all the habitat types. For example, these estuaries may never have had eelgrass beds. However, habitat diversity is a critical component of many of the larger estuaries (e.g., Coos, Tillamook), where certain more sensitive habitat types were more likely to have been lost due to development. Thus we accounted for the need to have the appropriate diversity of habitats in each estuary by using the measure of potential habitat under the habitat extent indicator.

4. *Water and Sediment Quality.*

a. Ecological Role

Water ties together all of the estuarine habitats described above, and is the conduit by which plant propagules, animals, sediment, nutrients, and organic materials move between the ocean and freshwater. The diversity of species found in estuaries relies on specific water chemistry conditions that vary spatially across the estuary and temporally from one season to the next. Many water chemistry parameters can be moved out of their natural range of variability because of development surrounding estuaries as well as the human land and water uses within the estuary and in the watershed. These uses often impair water quality and threaten the viability of estuary-dependent organisms.

The two most common types of water quality impairment are nutrient loading of water that leads to estuarine eutrophication and contaminant loading that usually results in sediment contamination and has direct effects on many estuarine species. As a result, the remainder of this section is split into the two broader groups of water quality and sediment quality. Too much or too little sediment also can impair water quality, but sedimentation is addressed in attribute #2.

Most contaminants and nutrients that impair water quality come from land use activities in the watershed and adjacent to the estuary. Agricultural land use is associated primarily with nutrient inputs from fertilizers and feed lot runoff and pesticide inputs. Urban and industrial landuse is associated with petroleum and other industrial contaminants, nutrient inputs from septic systems, water treatment facilities, and fertilizer use, and with pesticide inputs. Nutrients also come from offshore upwelling which moves into the estuaries particularly during the summer (Lee et al. in press).

The susceptibility of an estuary to water quality impairment depends on 1) the relative amount of water coming from the watershed (freshwater) compared to the ocean (salt water); 2) the amount of disturbance in the watershed; 3) the degree of mixing in the estuary , and 4) whether or not there is a bar or spit that closes off the estuary mouth from oceanic inputs during the growing season. Estuaries that are well-mixed and quickly flushed are less vulnerable to developing degraded water quality (EPA 2005). In comparison to the rest of the continent as well as estuaries globally, Oregon estuaries have low susceptibility to eutrophication (EPA 2005). This is because during the growing season (June-August), there is less precipitation and the bulk of the water and nutrients come from oceanic upwelling. During the rainy season, when most watershed-derived nutrients and contaminants are being flushed downstream, there is little primary production and these compounds are washed out to sea or deposited in estuarine sediments (Lee et al. in press).

The primary sediment contaminants of concern are pesticides, PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls), and heavy metals (Buchman 1999; EPA 2004; The H. John Heinz III Center for Science, Economics and the Environment. 2002). PAHs are by products of either petroleum- or coal-combustion that have been associated with increased presence of fish tumors. While those PAHs with low molecular weight degrade easily, they are acutely toxic to aquatic organisms. On the other hand, PAHs with higher molecular weights degrade less easily and are generally less toxic to aquatic organisms, even though some are known carcinogens (EPA 2006). PCBs formerly were used in electrical transformers and capacitors. They are toxic to biota and are also persistent, accumulating in sediments, fish, and other wildlife, thus posing a threat even to species higher on the food chain (EPA 2006).

Washington state has sediment quality standards based primarily on conditions in Puget Sound; Oregon does not have sediment quality standards (EPA 2006). There are no state sediment standards for pesticides currently monitored under the EMAP program by EPA, but DDT and DDE have sediment quality guidelines (EPA 2006).

b. Differences among estuary types

There are some factors in individual estuaries that make them more or less sensitive to water quality problems. In bar-built estuaries, the basin that forms behind the sand bar is a trap for pollutants which increases estuary susceptibility to water quality impairment if there is poor quality water feeding the estuary, for example from adjacent industrial uses.

Drowned river mouth estuaries receive more nutrients from the watershed than from the ocean, and thus are susceptible to water quality impairment if the watershed is highly disturbed (Lee et al. in press). Most nitrogen is processed in the bay if temperature and light conditions are good, and the rest is transported out to marine areas (Ryan et al. 2003). Thus eutrophication in these types of estuaries is less likely to be a concern.

Blind estuaries receive upstream nutrients. Low energy and large basin size lead to contaminant deposition in sediments. Due to the long residence times that generally occur in these types of estuaries, most nitrogen is cycled between sediments and the water column except during flood events. Seagrasses, when they are present, are important for nitrogen uptake (Ryan et al. 2003) and can help reduce the development of estuarine eutrophication.

The tidally restricted coastal creeks in Oregon are found in very small watersheds that generally have low population density. Therefore, they are not likely to develop poor water quality because there are few disturbances in the watersheds, unless there is significant agriculture adjacent to the stream or estuary.

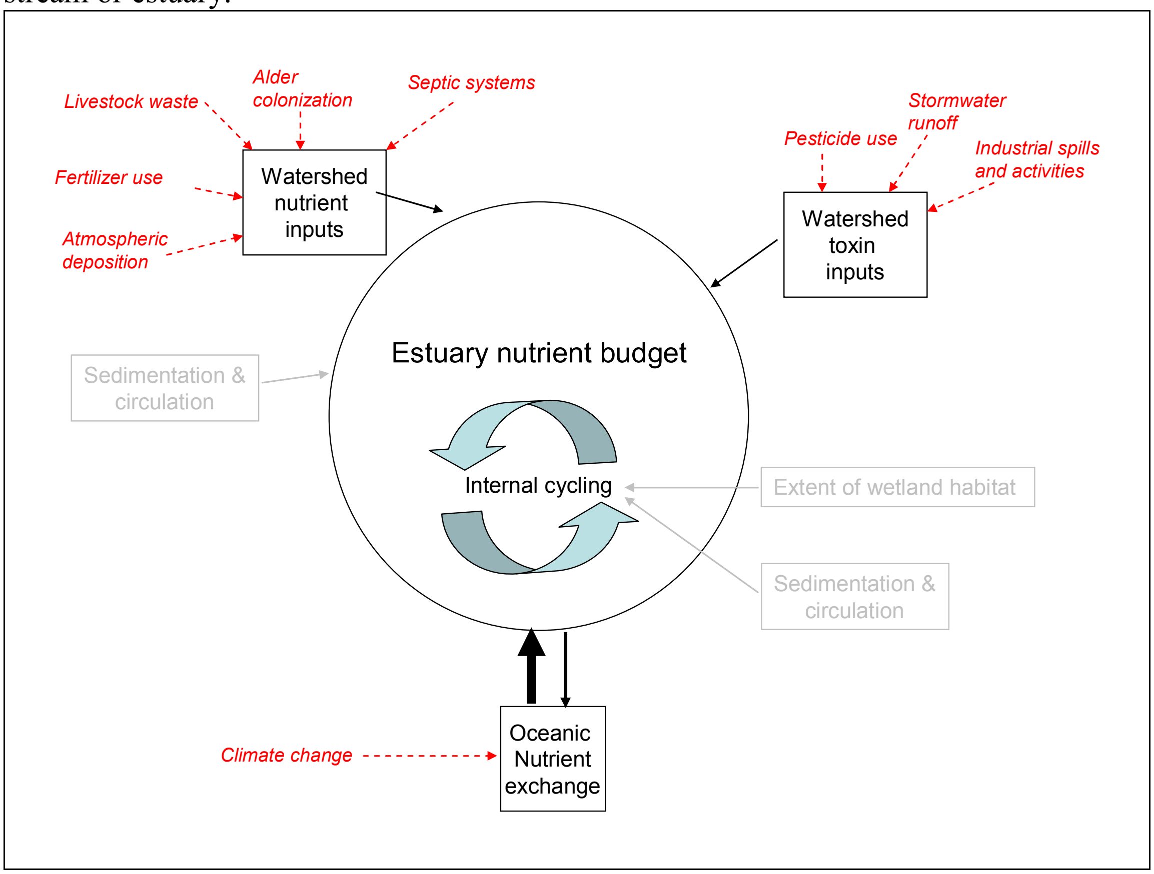


Figure 9. Conceptual ecological model of water and sediment quality. Indicators are in black. Threats to water or sediment quality are in red. Items in gray were addressed in other sections (e.g., sedimentation and circulation, wetland habitat, etc.)

c. Proposed Indicators:

Table 9: Indicators of water quality attribute. Relevant estuary types and the region of the estuary where the measurement should be made also are included. Measurements are proposed for each indicator. M=Marine; B=Bay; S=Slough; R=Riverine.

Indicator	Estuary type	Estuary region	Measurement
Watershed nutrient inputs	Blind and tidally-restricted coastal creeks	All [1]	Nitrogen Phosphorus Chlorophyll-a Water clarity (secchi disk) Dissolved oxygen
	bar-built	M, B, S [1]	
	river-dominated drowned river mouth	All [1]	
	tide-dominated drowned river mouth	B, S, R [1]	
Watershed toxin inputs – amphipod analyses	All	All [2]	Static 10-day acute toxicity test (EPA 2004)
Watershed toxin inputs – direct measures	All	All [2]	heavy metals, PAHs, PCBs, pesticides, TOC, sediment size

Notes:
1. If the water quality data are not currently collected by DEQ, only consider implementing additional water quality monitoring if there is reason to suspect water quality impairment, such as adjacent agriculture or industry, high population density, etc. This is particularly true for bar-built or tidally restricted coastal creeks.
2. Only consider implementing sediment toxicity testing if there are apparent threats in the watershed, such as adjacent industry.

Water Quality

Nitrogen and Phosphorus

Nitrogen (N) and phosphorus (P) limit estuarine primary production. Phytoplankton generally responds by increasing abundance with increased N loading (Schlesinger 1997), however, blooms of N-fixing cyanobacteria can occur when there is excessive P loading (Boynton et al.

1982). Therefore estuarine eutrophication can be driven by N and/or P loading. Nutrient sources are from offshore upwelling, watershed inputs, and internal cycling within the estuary itself. Nutrients can be exported to the ocean and/or deposited in estuarine sediments, and N specifically can be removed by denitrification in tidal wetlands.

Oceanic nutrient inputs vary seasonally. These patterns are governed by oceanic currents and temperatures both of which are vulnerable to change in response to climate change.

Under natural conditions, watershed nitrogen inputs are from nitrogen-fixing species such as soil bacteria or alder. Under developed conditions, these nitrogen inputs are increased by agricultural runoff of fertilizers and livestock waste, septic systems, atmospheric deposition, and increased alder colonization in riparian ecosystems after logging (Compton et al. 2003). Increased phosphorus loads also come from agricultural runoff of fertilizers and livestock waste and septic systems. Phosphorus can bind to sediments and be transported to the estuary where it is released as the more acidic river waters meet the more basic estuary water (Schlesinger 1997).

Much of the N and P inputs to an estuary comes from internal cycling. These patterns are governed by circulation and sedimentation processes. For example, mixing can stir up bottom sediments and release significant quantities of NH_4 (Schlesinger 1997).

Currently in Oregon estuaries, concentrations of N and P can be elevated during the growing season, but hypereutrophic conditions generally are not observed (Bricker et al. 1998). Most nutrient inputs from the watershed enter Oregon estuaries with flood events driven by winter rainfall. This influx of nutrients does not coincide with the growing season of estuary phytoplankton and as a result the nutrient load does not increase primary production which can lead to eutrophication. It is assumed that most of these watershed nutrients are moved out to sea during this time. During the summer growing season, when phytoplankton could respond to nutrient inputs by increasing productivity, most nutrient are coming from the ocean and not from the watershed (Lee et al. in press). Oceanic inputs are generally not high enough to produce high productivity and eutrophic conditions (Lee et al. in press).

Chlorophyll-a, Dissolved Oxygen
With increased nutrient loading comes an increase in the trophic status and an increase in primary production. An increase in primary production, measured as an increase in chlorophyll-a (Chl-a) concentration, leads to depressed dissolved oxygen (DO) when decomposing algae consume oxygen. This shift in trophic status is measured by an increase in Chl-a concentration and a decrease in dissolved oxygen (DO) concentration. High Chl-a and low DO stress fish and other aquatic organisms.

A shift to more eutrophic conditions is generally more of a problem in estuaries with long residence times and those that are seasonally closed off from the ocean by a bar or spit, as described above. Well-flushed estuaries, with water residence times measured in days to a few weeks may never experience lowered DO, even if nutrient inputs increase (Parrish et al. 2000). Thus we suggest conducting DO measurements in all but the drowned river mouth estuaries. At the moment, anoxia and hypoxia do not appear to be problems in Oregon estuaries (Bricker et al. 1998).

Water Clarity
Water clarity can be altered by elevated sediment loading and/or high rates of primary productivity in eutrophic estuaries. Rivers carry sediments from the watershed to the estuary, and as the water slows in the estuary, much of the sediment load is deposited (see attribute #2, sedimentation). Thus water clarity generally increases from the riverine region of an estuary to the marine region (Schlesinger 1997). However, if the sediment load is excessive, or if the water becomes eutrophic due to excess nutrient loading, resulting turbid waters can stress plankton and submerged macrophytes, which can impact all levels of the food web.

Water Quality Data Collection
The Oregon Department of Environmental Quality collects data on all five of these parameters in estuaries in Oregon. We propose to use their protocols and data to measure water quality. Existing data on Oregon estuaries, collected by the ODEQ and EPA, may soon be available at the Pacific Northwest Water Quality Data Exchange website (http://deq12.deq.state.or.us/pnwwqx/Search.aspx). However, currently data are best retrieved from the LASAR (Laboratory analytical storage and retrieval) website run by DEQ (http://deq12.deq.state.or.us/lasar2/default.aspx) and the STORET website run by EPA (http://www.epa.gov/storet/dbtop.html).

Sediment Quality
Two approaches have been developed for measuring sediment toxicity. One involves testing the toxicity of the sediments to an invertebrate species and the other involves directly measuring specific parameters and comparing those values with established thresholds.

For estuaries where no data collection occurs through either EPA or ODEQ, we suggest evaluating the landuse conditions within the watershed and the estuary to evaluate the risk of sediment contamination. If landuses do not exist that would be likely to produce sediment contamination, then no further evaluation may be needed at this time, although changes in landuse activities should be carefully monitored. If potential risky landuses are present, then it may be necessary to sample for the most likely contaminants; however completing these tests (either the amphipod toxicity test or the sediment analysis tests) requires strict adherence to protocols, use of certified laboratories with good quality control measures, and a budget that allows for repeated testing over time.

Sediment Toxicity Using Amphipods: Sediment toxicity can be evaluated using the percentage of the amphipod *Ampelisca abdita* that survives 10 days in sediments from the test site, termed a static 10-day acute toxicity test (EPA 2004). The sediments are deemed toxic if the amphipods have less than 80% control-corrected mean survival rate. It is important to also measure total organic carbon (TOC) and the abundance of fine particles in the sediment. TOC concentrations indicate the availability of food to amphipods and fine particles allow the amphipods to grow naturally. In Oregon, the only 'toxic' site tested to date was the Siuslaw River, however, the result was due to low TOC (0- 0.01%) and low fines (<1%) which interfere with tube formation for the *Ampelisca*. So this test result may not indicate contaminated sediments per se.

Sediment Toxicity Using Direct Sediment Analyses: NOAA has developed thresholds for sediment concentrations of organic and inorganic compounds (http://response.restoration.noaa.gov/book_shelf/122_squirt_cards.pdf).This includes heavy metals, petroleum products, pesticides, and other compounds. Thresholds indicate ecological risk to an area. Online resources include analytical methods, ERLs (effects range-low) and ERMs (effects range-median). The standards are not regulatory standards but meant to provide some guidance on toxicological affects to fish and other aquatic organisms.

In Oregon a number of estuaries are already monitored by EPA's EMAP program: Tillamook, Coos, Rogue, Umpqua, Siuslaw, Yachats, Rock Creek, Alsea, Yaquina, Salmon, Siletz, Nestucca, Little Nestucca, Netarts, and Nehalem in addition to the Columbia and a number of sub-estuaries of the Columbia. These data are stored on STORET (http://www.epa.gov/storet/dbtop.html). When working in these estuaries, we suggest relying upon these data and examining the reported values relative to the thresholds provided by NOAA. In addition, the trends in reported values could be used to evaluate the trajectory of an estuary over time (Ward et al. 1998).

DISCUSSION

In this assessment, we provide the foundation for conservation planning in estuaries along the Oregon coast. Here we propose a framework for developing the ecological component of a conservation plan for estuaries in Oregon. The framework is largely structured on physical attributes that should be functioning for the estuary as a whole to be ecologically viable. The attributes include the hydrologic and sediment regimes, water quality, and the matrix of habitats.

The next step for any particular location is to identify data sources to quantify the attributes and indicators, and develop thresholds for viability ranging from good to poor. During this process, we anticipate that the attributes, indicators, and measurements will need to be refined.

As we mentioned in the introduction, all of the attributes discussed in this document are critical for salmon persistence and population recovery. However, these planning products are not intended to replace a conservation plan designed specifically for Pacific Northwest salmonids. Such a plan would need to consider the specific ecological requirements of the life history stages of the six anadromous salmon and trout species native to Oregon coastal watersheds. Nonetheless, estuary conservation and restoration projects that can be monitored using this framework are likely to contribute to salmon recovery because of the key role played by estuaries in the salmon life cycle.

NOAA-Fisheries produced a recovery plan module for the Columbia River estuary (NOAA 2007) that contains some similar concepts to this assessment. Table 10 below is a cross-walk between those two efforts.

Table 10. Crosswalk between NOAA "limiting factors" (NOAA 2007) and TNC "key ecological attributes" for the Columbia River estuary.

NOAA Fisheries Ranking	Limiting Factor	Description	Crosswalk to TNC KEAs
top	flow-related estuary habitat changes	size & timing of instream flows & tides – this affects habitat connectivity and timing of fish physiological transformation	Hydrologic regime
top	flow-related changes in access to off-channel habitat	overbank flow and connectivity to floodplain	Habitat extent / distribution / connectivity; also hydrologic regime?
top	reduced macrodetrital inputs	mostly come from emergent wetlands; most detrital inputs occur during overbank flooding	Habitat extent / distribution / connectivity?
top	water temperature	salmon need cool water	not currently included under water quality, but could be added
top	flow-related plume changes	Plume imp area for fish growth, fish physiological transitions, estuary productivity; threats to plume include changes in surface area, volume, frontal features.	Hydrologic regime
high	bankfull elevation changes	volume of water required for overbank flow; this volume has increased b/c of levees	Habitat extent / distribution / connectivity; hydrologic regime
high	sediment/nutrient-related estuary habitat changes	sediment deposition and erosion (also affects microdetritus attached to sediments – see increased microdetritus threat below)	sediment regime
high	native pinnipeds	predation threat	n/a
high	short-term toxicity	e.g., polycyclic aromatic hydrocarbons (PAHs)	not currently included under water quality, but could be added
high	native birds	predation threat (e.g., terns)	n/a
medium	bioaccumulation toxicity	contaminants that bioaccumulate (e.g., DDT, PCBs)	not currently included under water quality, but could be added

low	increased microdetrital inputs	mostly decaying phytoplankton from reservoirs – these decrease estuarine productivity	land use piece of sediment regime sort of gets at it but not really??
low	sediment/nutrient-related plume changes	sediments and nutrient affect ocean productivity	sediment regime
low	Stranding	threat	n/a
low	native fish	threat	n/a
lowest	exotic plants	threat	Habitat extent / distribution / connectivity
lowest	introduced invertebrates	threat	n/a
lowest	exotic fish	threat	n/a

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