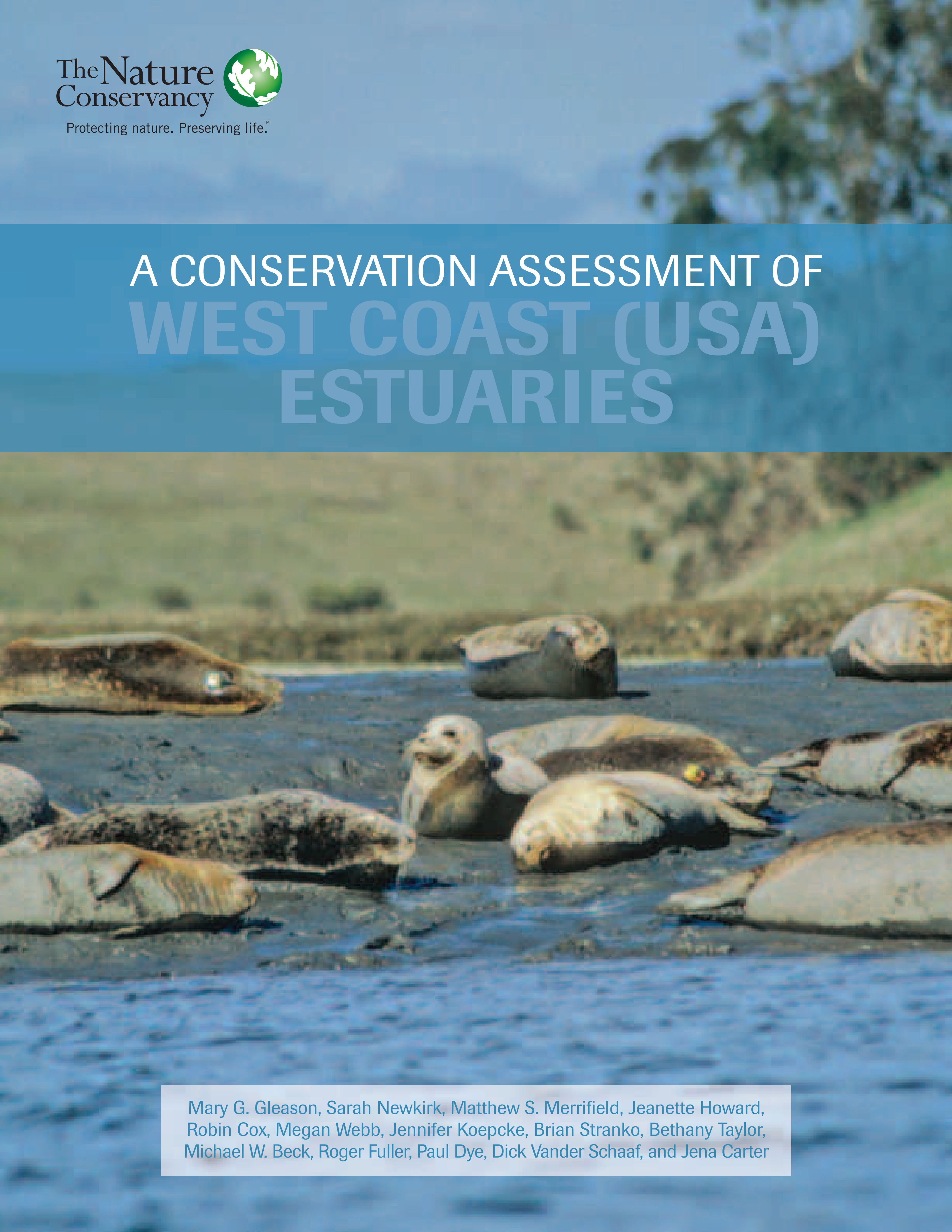


The Nature Conservancy

Protecting nature. Preserving life.™

A CONSERVATION ASSESSMENT OF WEST COAST (USA) ESTUARIES

Mary G. Gleason, Sarah Newkirk, Matthew S. Merrifield, Jeanette Howard, Robin Cox, Megan Webb, Jennifer Koepcke, Brian Stranko, Bethany Taylor, Michael W. Beck, Roger Fuller, Paul Dye, Dick Vander Schaaf, and Jena Carter

CONTENTS

SUGGESTED CITATION

Gleason MG, S Newkirk, MS Merrifield, J Howard, R Cox, M Webb, J Koepcke, B Stranko, B Taylor, MW Beck, R Fuller, P Dye, D Vander Schaaf, J. Carter 2011. *A Conservation Assessment of West Coast (USA) Estuaries*. The Nature Conservancy, Arlington VA. 65pp.

ACKNOWLEDGEMENTS

We appreciate the input of the many colleagues who contributed to this assessment by providing data, comments, and recommendations based on their personal and professional experience. We also thank the many conservation practitioners, managers, and stakeholders who are working diligently to conserve and restore estuarine ecosystems on the West Coast. Funding for this assessment was provided by the David and Lucile Packard Foundation.

FUNDED BY

The David and Lucile Packard Foundation

EXECUTIVE SUMMARY

© Bridget Besaw

The land-sea interface is one of the most ecologically rich and complex areas on Earth. Occupying the unique zone where terrestrial, freshwater, and marine realms converge, estuaries are shaped by complex exchanges of energy, water, nutrients, sediments, and biota. They are enormously productive areas, providing habitat for an extraordinary array of fish, shellfish, birds, and mammals.

Coastal areas where estuaries are found are also home to more than sixty percent of humanity. This isn't a coincidence: people gravitate toward coastal areas because they provide numerous ecosystem services upon which we depend. However, dense human habitation comes with a cost—temperate estuaries are some of the most degraded environments on the planet, making their protection and restoration a top conservation priority.

While significant progress has been made over the past few decades in improving estuarine water quality, restoring wetland habitats, and incorporating estuarine habitats into managed areas, estuarine conservation efforts along the United States (U.S.) West Coast—including Washington, Oregon, and California—have generally proceeded on a bay-by-bay basis, with relatively little coordination among sites or across the region. In addition, conservation planning for estuaries has not historically been well integrated across terrestrial, freshwater, and marine realms to address cross-realm threats to estuarine health. Given the strong similarities in basic ecology and threats faced by many of the region's estuaries, a coordinated effort to assess regional patterns and develop integrated multi-site strategies is likely to improve conservation effectiveness at both the local and regional scales.

This assessment outlines an enhanced planning approach for West Coast estuaries that incorporates an evaluation of the regional context for estuarine conservation and recommends an approach to site-scale planning with more focus on ecological processes and functions. At the regional scale, conservation planning should seek to provide context (status of conservation targets, distribution of threats, management and ownership patterns, conservation opportunities) supporting conservation investment at individual estuaries, as well as to identify groupings of estuaries that share similar features (conservation targets, threats, ownership patterns, type of estuary) for multi-site conservation strategies. At the site scale, conservation plans should aim to maintain the full spectrum of estuary zones, processes and functions; safeguard critical connections among terrestrial, freshwater, and marine realms; and safeguard ecosystem service values. At the same time, site-scale efforts should be grounded in a regional context and geared toward delivering conservation outcomes that have relevance at scale. Further, ecological linkages should be considered when developing conservation action plans to promote the long-term viability of estuaries. Rather than using only species- and habitat-level conservation targets, an enhanced conservation planning approach for estuaries should incorporate ecological processes, functions, and other system-level conservation targets that integrate across terrestrial, freshwater, and marine realms. Understanding how different stressors act to alter those processes and functions is critical to developing effective conservation strategies.

This assessment is based, in part, on a geographic information system (GIS) database that contains spatial data for 146 estuaries and their associated catchments (adjacent watersheds) in California, Oregon, and Washington. The West Coast Estuary Database provides regional data for characterization of spatial patterns of the distribution of selected biodiversity targets and threats. This database, available to both technical and non-technical users (go to http://www.tnccmaps.org/estuaries for more information), includes 27 variables that characterize some key biophysical and human use parameters of these estuaries.

A hierarchical classification system was developed for West Coast estuaries that identified three regions (based on climate, latitude, and oceanography) and four estuary types distinguished by the relative degree of influence of the hydrodynamic forcing mechanisms of waves, tides, and rivers. While some estuaries exist along a continuum that is influenced strongly by seasonal or latitudinal patterns, West Coast estuaries were classified into one of four types:

- *River mouth estuaries* are dominated by river energy;
- *Coastal lagoons* are dominated by wave energy;
- *Tidal bay estuaries* are deeper-water features that are dominated by tidal energy; and
- *Classic estuaries* are influenced by all three controlling factors (river, tide, wave).

These predominant hydrodynamic energy sources play a key role in structuring estuaries and influence their susceptibility to different threats.

© Steve Mlodinow

Regional scale characterization of the distribution of biodiversity, threats and human uses, ownership, and existing protected lands and waters provides context for the development of conservation strategies. Patterns of distribution of some elements of biodiversity, such as wetlands, floodplains, Important Bird Areas, and Salmon Strongholds, were characterized for the region. There are roughly 700,000 acres of tidal and freshwater wetlands in estuarine watersheds in the region, with especially high concentrations in San Francisco Bay, Puget Sound, and Coos Bay, OR. While some West Coast estuaries are characterized by a great deal of floodplain or wetland habitat, a large amount of these habitats has been converted to urban and agricultural land cover, reducing current distribution to a fraction of historical extent. West Coast estuaries are important nursery areas for juveniles of many marine fish and invertebrates. Because a regional assessment of nursery habitat for marine fish has not yet been completed, this assessment assembled a database documenting presence of juveniles of selected commercially-important species in West Coast estuaries. Formerly-extensive native oyster beds have been reduced to remnant populations in most bays in the study area. Finally, West Coast estuaries are key habitat for salmonids; the Columbia River, Klamath River, Whidbey Basin, and San Francisco Bay Delta estuaries rank the highest in numbers of robust salmonid populations.

Several key threats to estuaries were identified for the region:

- Altered tidal exchange
- Altered nutrient dynamics and water quality
- Altered freshwater inputs
- Altered sediment regime
- Invasive species
- Direct habitat loss
- Climate change

Human beings are an undeniably prominent feature of the landscape and seascape of West Coast estuaries. Agriculture and forestry dominate the catchments of many estuaries, while others have large urban centers, and still others remain in a largely natural state. An understanding of patterns of land tenure (ownership), land cover, and predominant land uses in estuary catchments is essential for strategy development as these parameters represent different threats and different opportunities for conservation.

Patterns of public and private land ownership influence conservation and stewardship efforts in the region. Private land dominates the upland catchment areas; the main private landowners on a per acre basis are timber companies. Overall, managed lands account for only 25% of the total area of estuary catchments in the region, however 60% of estuaries have at least 10% of their catchments in managed areas. Only 8% of open water and marshes associated with estuaries are in marine managed areas, and only 11% of estuaries have at least 50% of their open water and associated marsh habitats under some sort of marine managed area designation. The most significant management agency for open water or marshland is the federal National Wildlife Refuge System of the U.S. Fish and Wildlife Service, which represents 6% of the total area of open water and marshes in West Coast estuaries.

Conservation of West Coast estuaries advances through both site-scale strategies with local actions and through multi-site strategies (policy, funding, export of successful pilot projects) that can scale up to benefit multiple sites. The data in this assessment can be used to identify groups of estuaries that share similar features, such as key conservation values (biodiversity elements), threats, estuary type, and ownership patterns that make them amenable to similar strategies. This multi-site planning approach can be used to prioritize sites to advance a suite of strategic pathways and is demonstrated herein.

Finally, conservation of West Coast estuaries will be enhanced by development of a shared regional vision, goals, and suite of strategic pathways that can help to organize conservation actions of multiple partners. As a starting point, a proposed regional vision and goals follows.

Regional Vision: Key ecological processes, functions, and ecosystem services are maintained or restored in estuaries throughout the West Coast region to protect the full range of ecological and human use values.

- **Goal 1) Establish a regional estuaries program for the West Coast under the authority of a lead federal agency, to provide a policy framework, set regional indicators and milestones, administer funding, develop a body of practice, and convene a network of practitioners.**
- **Goal 2) Achieve a 20% increase in acreage of West Coast estuary catchments, waters, and marshes under conservation—as defined by intact ecological processes, functions, and ecosystem services—by 2025 through protection, restoration, and stewardship by public agencies or private conservation agreements.**
- **Goal 3) Promote and test incentives, easements, and innovative approaches focused on securing habitat and ecological processes while maintaining profitable human uses on working waterfronts and landscapes.**
- **Goal 4) Plan for and implement ecosystem-based adaption strategies to promote climate change resilience in natural and human communities in estuaries.**
- **Goal 5) Fund research and pilot projects to improve our understanding of the functions and values of estuaries, critical threats to estuaries, and the conservation effectiveness of restoration and stewardship practices.**

1. INTRODUCTION

© Paul Zaretsky

The land-sea interface, a narrow zone where terrestrial, freshwater, and marine realms converge, is one of the most ecologically rich and complex areas on Earth. Perhaps no ecosystem is more characteristic of the land-sea interface than the estuary—a system where complex exchanges of energy, water, nutrients, sediments, and organisms create dynamic and productive habitats and unique species assemblages with ecological linkages that span realms. An estuary is a semi-enclosed coastal body of water that has a free connection with the open sea at least intermittently, and within which the salinity of the water is measurably different from the salinity in the open ocean, as a result of dilution by land-derived freshwater (Pritchard 1967). Mixing of salt and freshwater within an estuary generally varies with tidal action and freshwater input from river or stream discharge; salinity may periodically be higher than that of the open ocean due to evaporation. A defining feature of estuaries is the influence of dynamic forces—including tides, precipitation, freshwater runoff, evaporation, and wind—that affect the exchange of organisms, detritus, nutrients, toxins, and sediments across the land-sea boundary.

Estuarine environments are some of the most productive areas on Earth, producing high amounts of organic detritus that is an important food source for resident and migratory species in estuarine and coastal waters. Estuarine biodiversity is characterized by resident species that can tolerate the range of salinity and tidal conditions, as well as transitory species that spend part of their life cycle in estuaries. Estuaries provide critical resting and feeding sites for migrating birds and marine mammals; they support millions of shorebirds and waterfowl during spring and fall migrations and during the winter months. For anadromous fishes that move between marine and freshwater realms, estuaries are important conduits between the watersheds and the ocean during their complex life cycles. Estuaries are also important nursery habitats for many marine species, sheltering an abundance of juvenile shellfish and fishes as they mature.

Estuaries are exceedingly valuable for the biodiversity they harbor, as well as for the ecosystem services they provide and upon which people depend. These benefits include filtering water, buffering against a rise in sea level, providing food and recreation opportunities, serving as natural barriers to erosion, and protecting water quality (**Text Box 1**). Because estuaries are at the receiving end of rivers and streams, they serve as buffers between the ocean and land, filtering sediments and pollutants from waters before they enter the ocean. Indeed, the global value of services from seagrasses and estuarine and coastal wetlands is estimated to be ten times higher than that of any terrestrial ecosystem (Costanza et al. 1997).

Despite their enormous importance and value to both biodiversity and humans, estuaries represent some of the most degraded habitats in the temperate realm and continue to be stressed by threats from both land and sea (Lotze et al. 2006; Airoldi and Beck 2007; Halpern et al. 2008). Indeed, estuaries are highly threatened largely as a consequence of their exposure to the combined impacts of human activities on the ocean, on land, and in freshwater (Kennish 2002; Airoldi and Beck 2007; Sloan et al. 2007; Halpern et al. 2009). Coastal areas are home to the majority of humanity; as much as 75% of the world's population is expected to reside in coastal areas by 2025 (Agardy et al 2005; Airoldi and Beck 2007). Worldwide, habitat destruction is particularly severe in coastal ecosystems where human activities have been historically concentrated and estuarine health is significantly influenced by the condition of surrounding watersheds (Howarth et al. 2002; Kennish 2002; Knottnerus 2005; Lotze et al. 2006). Evaluation of trends across 12 temperate estuarine and

TEXT BOX 1: ECOSYSTEM SERVICES OF HEALTHY ESTUARIES

Ecosystem services are the many benefits that natural ecosystems provide to people (Agardy et al. 2005). Estuaries provide an extraordinary range of such services, when their ecosystems are healthy and functioning. Ecosystem services of estuaries include:

- **Provisioning food**: Estuaries provide habitat and nursery grounds for commercially and recreationally important finfish and shellfish; sites for shellfish aquaculture; and hunting areas for waterfowl.
- **Waste and runoff treatment**: Estuarine marshes improve ambient water quality by filtering water through marsh plants and peat, and removing pollutants such as herbicides, pesticides, and heavy metals, as well as excess sediments and nutrients.
- **Recreation**: Estuaries provide opportunities for hunters, birdwatchers, hikers, kayakers, and other recreational users.
- **Protection from natural hazards**: Estuaries and their surrounding wetlands stabilize shorelines and protect coastal areas, inland habitats, and human communities from flooding, erosion, and inundation. When flooding does occur, estuaries often act like huge sponges, soaking up the excess water.
- **Transportation and marine operations**: Many estuaries serve as sheltered or deep-water ports and harbors, providing important loci for marine commerce and transportation.
- **Aesthetic and cultural**: Estuaries provide natural viewsheds and historic values that may enhance property values in adjacent areas, and provide spiritual renewal and cultural significance.

Because people value these services so highly, estuaries provide a unique opportunity to introduce an ecosystem services approach to conservation. This approach simply means considering people's well-being at some point in the planning and/or implementation of a conservation project. One way to accomplish this is by assessing the economic value of the benefits people receive from natural resources. This valuation allows for protection of ecosystem services to be discussed using the same currency that is applied to other social values, permitting decision-makers to rationally compare benefits and costs (NRC 2005). However, ecosystem service approaches do not necessarily have to involve payments, markets, or valuation. At a minimum, planners may simply acknowledge and demonstrate the multiple benefits that can result from conservation.

coastal ecosystems in Europe, North America, and Australia shows that estuaries have undergone global decline, despite wide geographic distribution and unique regional histories (Lotze and Muir 2009).

State of West Coast Estuaries

The West Coast of the United States including Washington, Oregon, and California encompasses well over 140 estuaries (hereinafter "West Coast estuaries") and a diversity of estuarine ecosystems (**Figure 1-1**). The geomorphic origin of West Coast estuaries varies from large, deep, glacially-carved fjords (such as Puget Sound, Washington), to drowned river valleys (such as Willapa Bay, Columbia River, and many others), to bar-built estuaries (such as Netarts Bay, Oregon), to small shallow lagoons associated with relatively flat topographical features and low freshwater inflows (such as Mugu and Batiquitos Lagoons in southern California; Emmet et al. 2000). Estuarine ecosystems on the West Coast have been impacted as land use and other human activities in the catchments have altered ecological processes, destroyed wetland and coastal fringe habitats, and affected ecosystem structure and function. California has lost over 90% of its coastal wetlands, and the West Coast generally has lost almost all native shellfish beds (Nichols et al. 1986; Kirby 2004; Van Dyke and Wasson 2005; Dahl 2006; Beck et al. 2009; Beck et al 2011). The timing, quantity, and quality of freshwater flows down rivers and into estuaries have been significantly altered by dams, diversions, and habitat alteration in the watersheds. Dams, levees, and shoreline armaments have disrupted sediment exchange between rivers and the marine ecosystem, and from the marine ecosystem onto land. Many estuaries have had their openings to the sea manipulated or armored with jetties for port and harbor development. Salmon and steelhead, which are dependent on estuarine ecosystems, are at historic low abundances and some populations are listed as threatened or endangered. Exotic, invasive species are altering estuarine habitats all along the West Coast; more frequent harmful algal blooms are affecting shellfish harvesting; pollution (particularly from non-point sources) continues to affect estuarine water quality. In addition, the growing concern over projected climate change impacts on estuaries warrants a new focus on climate change adaptation in coastal ecosystems. Climate-induced changes such as sea level rise; altered timing and amount of freshwater, nutrients, and sediment delivery; higher water temperatures; increasing ocean acidification; and changing species compositions will complicate conservation efforts in estuarine systems (Scavia et al. 2002; Callaway et al. 2007; Mawdsley et al. 2009; Zedler 2010).

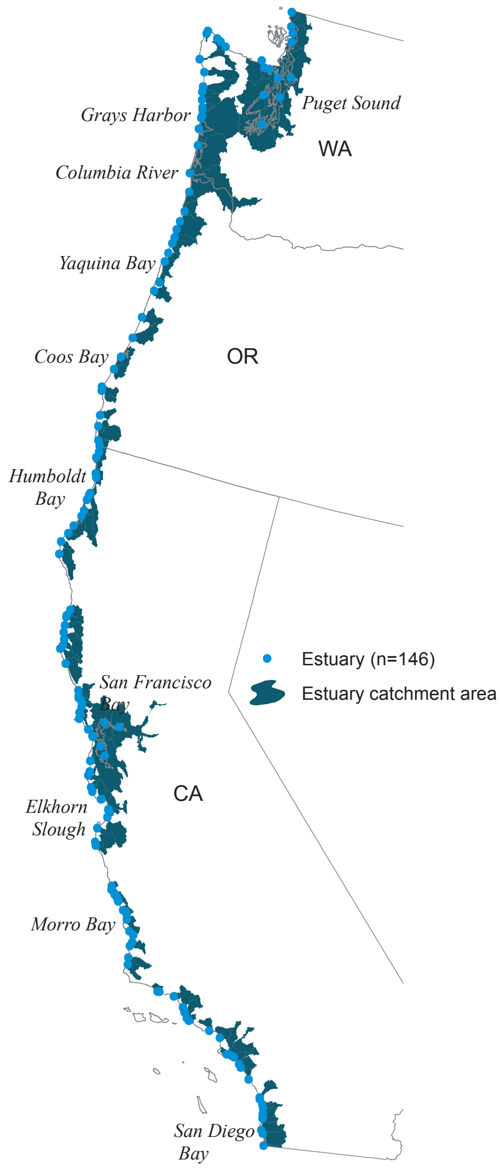


Figure 1-1: Distribution of estuaries included in the West Coast Estuary Assessment

West Coast estuaries should be considered a high priority for conservation and restoration, both because of the intrinsic value of their biodiversity and important ecological functions, and also because of the ecosystem services they provide to human communities along the coast (Wilson and Farber 2009). Despite some extinctions and substantial population declines of some West Coast estuarine species and functional groups, most species and habitats persist, though often in greatly reduced abundance (Frissel 1993; Kirby 2004; Beck et al. 2009). Where human efforts have focused on protection and restoration, recovery of estuarine species and their habitats has occurred (Josselyn et al. 1990; Lotze et al. 2006; Gee et al. 2010).

Conservation Challenges in Estuarine Settings

Conservation of estuaries is complicated not only by their dynamic biophysical conditions, but by the obstacles to applying traditional conservation planning approaches in these transition zones that span terrestrial, freshwater, and marine realms (**Figure 1-2**; Stoms et al. 2005; Sloan et al. 2007; Tallis et al. 2008; Beger et al. 2010). Many of the key threats to estuaries are regional in scope and span the land-sea interface (e.g., forestry, agriculture or land use policies; population and development pressures; inadequate public land management; land-based pollution inputs).

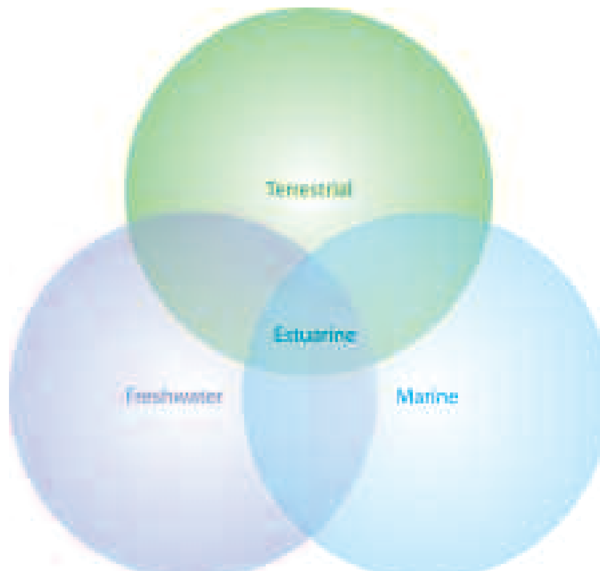


Figure 1-2: Estuaries are at the intersection of realms

In addition, conservation opportunities, stakeholders, and policies have been traditionally associated with either terrestrial or marine systems, but rarely both, complicating the implementation of even the most integrated conservation plan. Despite a range of concerted management and conservation efforts, West Coast estuaries are still under-protected and degraded relative to many other temperate ecosystems. Limited capacity, jurisdictional boundaries, and political considerations have generally led to piecemeal, "bay-by-bay" conservation (Beck et al. 2001; Leschine et al. 2003; Sloan et al. 2007). Currently, there is no framework for setting priorities or establishing a conservation agenda at a regional scale that can inform site-scale actions in West Coast estuaries (Zedler 1996; Leschine et al. 2003; Halpern et al. 2009). Although each estuary has a unique set of conditions and likely will require site-level actions, a better understanding of the regional context of West Coast estuaries can help to identify common themes and needs that can lead to high leverage multi-site strategies. For example, an understanding of shared characteristics among West Coast estuaries—together with demonstration of innovative conservation approaches at a site level—can help create the enabling conditions (i.e., funding, policies, partner engagement, etc.) for application of beneficial conservation approaches at a multi-site scale (Merrifield et al. 2011).

A handful of estuarine conservation efforts underway on the West Coast provide examples of successful strategies and lessons learned, but have also experienced difficulties in coordinating regionally. The National Estuary Program (NEP) promotes comprehensive planning to protect nationally significant estuaries, although it only includes six estuaries on the West Coast. The National Estuarine Research Reserve (NERR) system focuses on estuarine research at priority sites, but only includes five estuaries on the West Coast. While both of these programs are administered by the federal government, their goals are different and they are led by different agencies. The West Coast Ecosystem-Based Management (EBM) Network is a partnership of six community-based initiatives organized in 2008 to share lessons and practices in ocean, coastal, and watershed management, but it was not designed to achieve coordination in regional estuary conservation. Ongoing regional efforts have promise—specifically, the agreement among the three West Coast governors to focus on protection and restoration of coastal habitats, EBM, and sustainable coastal communities (West Coast Governors Agreement 2008)—but their potential has yet to be realized.

Purpose of this Assessment

This assessment aims to advance effective conservation of West Coast estuaries by providing a regional database and characterization of estuaries, guidance on enhancing conservation planning and strategy development across realms and scales, and a regional vision and goals. A number of conceptual principles informed this work. First, focusing on ecological processes and functions of estuaries is an effective means of integrating threats and strategies across realms. Second, different types of estuaries may be more or less susceptible to different threats, and multi-site strategies can be developed by Third, by understanding the regional context, practitioners can augment their existing site-scale actions and identify leveraged, multi-site conservation strategies.

This assessment is grounded in The Nature Conservancy's (TNC) regional and site-scale planning approaches and the Open Standards for Conservation Action Planning.[1] The geographic scope of the assessment includes 146 estuaries in California, Oregon, and Washington (**see Appendix A**); estuaries to be included were identified based on the National Wetland Inventory mapping of estuarine habitat or vegetation types. In order to analyze the conservation status of, and threats to, estuaries over such a large region, we created a geographic information system-based (GIS) spatial database for these estuaries and their catchments. Estuary catchments were defined as all the adjacent watersheds (at the hydrologic unit code 10 level) that border each estuary. We compiled spatial data on 27 variables describing the geographic features, biodiversity, threats, ownership, and human uses of West Coast estuaries and their catchments (**see Appendix B** for details). The spatial database and map server are publicly available online (**Text Box 2**).

This assessment aims to both inform and extend the reach of existing estuarine conservation efforts and includes the following main components:

- **Enhanced conservation planning approach for estuaries**: an enhancement of traditional conservation planning approaches that will result in more integration across geographic scales (regional and site-specific) and across realms (terrestrial, freshwater, marine) with a focus on maintaining or restoring ecological processes and functions of estuaries.
- **Classification system for West Coast estuaries**: a hierarchical classification system incorporating regional differences along the West Coast and an approach to estuarine typology that distinguishes among four types of estuaries that vary in the relative influence of river, wave, and tidal energy forces.
- **Regional characterization of West Coast estuaries**: a regional assessment of patterns of biodiversity, ownership and management, threats and human uses, and situational context that provide a foundation for priority-setting and multi-site strategies.
- **Strategic pathways for advancing conservation:** an approach to evaluating and grouping estuaries based on shared characteristics of biodiversity values, threats, type of estuary, and ownership to inform multi-site or high-leverage strategies that benefit multiple sites; and an overview of some key opportunities for action.
- **A conservation vision for West Coast estuaries**: a vision and set of goals and preliminary recommendations for advancing estuarine conservation along the West Coast.

TEXT BOX 2: ACCESSING THE WEST COAST ESTUARY SPATIAL DATABASE

A geographic information system (GIS) database containing spatial data for 146 estuaries and their associated catchments in California, Oregon, and Washington is available to both technical and non-technical users. The database includes 27 variables that characterize some key biophysical and human use parameters for West Coast estuaries. GIS analysts can download the entire database as an ESRI geodatabase or KML. Non-technical users can visualize the information using a web-based map viewer. Go to http://www.tnccmaps.org/estuaries for more information.

[1] http://www.conservationmeasures.org/initiatives/standards-for-project-management

2. CONSERVATION PLANNING FOR WEST COAST ESTUARIES

© Central Coast Wetlands Group at Moss Landing Marine Labs

The physical link estuaries provide between realms creates a compelling setting for the integration of terrestrial, freshwater, and marine conservation planning at both the regional and site scales (Stoms et al. 2005, Sloan et al. 2007, Tallis et al. 2008; Beger et al. 2010). Traditional conservation planning approaches[2] need to be carefully tailored to address this unique context. Site-scale conservation actions at individual estuaries will be most effective if cross-realm linkages and threats are addressed by strategies that span the land-sea interface. To achieve regional outcomes, some conservation strategies at the site scale should be aligned with regional strategic priorities to ensure that local conservation actions are scaling up to address important regional outcomes. A better understanding of the regional context will facilitate this approach.

At the regional scale, conservation planning should seek to provide context supporting conservation investment at individual estuaries, as well as identify groupings of estuaries that share similar characteristics (such as biodiversity, threats, land cover, public ownership, etc.) that can then be used to promote cross-learning among similar sites and the identification of multi-site strategies that would benefit a group of estuaries (Merrifield et al. 2011). A multi-site strategy is one that accomplishes effective conservation of multiple estuaries simultaneously. Such a strategy might be a policy change to improve the enabling conditions for estuarine restoration or conservation projects. It might be the creation of a new funding stream aimed at estuarine habitat protection. Or, it might be a site-level demonstration project that is designed for ultimate implementation at multiple sites.

A regional assessment provides a foundation for developing effective multi-site conservation strategies across the region by characterizing broad patterns of the distribution of conservation targets (the biodiversity elements whose protection or restoration is the conservation goal) and threats (the key stressors of those targets and their underlying causes), and by characterizing regional patterns of land use and ownership, laying a foundation for identifying key partners and opportunities.

At the site scale, conservation plans should aim to maintain the full spectrum of estuary zones, processes, and functions; safeguard critical connections among terrestrial, freshwater, and marine realms; and safeguard ecosystem service values. At the same time, site-scale efforts should be grounded in a regional context and geared toward delivering conservation outcomes that have relevance at scale. Over the past 15 years, TNC has developed a conservation planning methodology that leads multi-disciplinary teams through an analysis of ecological and human factors for safeguarding biodiversity. This approach, known as Conservation Action Planning (CAP)[3], strikes a balance between scientific rigor and conservation practicality, using systematic and intuitive standards and guidelines (**Text Box 3**). The CAP process can be enhanced to make it more relevant for use in estuaries through a greater focus on ecological processes and functions and by conducting situational analyses with an eye towards both landward and seaward stakeholders and opportunities. By developing a regional conservation agenda of shared conservation goals for West Coast estuaries, limited capacity and funding could be better allocated

[2] http://www.conservationmeasures.org/initiatives/standards-for-project-management
[3] http://conserveonline.org/workspaces/cbdgateway/cap/resources/index_html

TEXT BOX 3: KEY STEPS OF CONSERVATION AREA PLANNING (CAP)

The CAP process guides project teams to develop appropriate conservation strategies, and provides an objective, consistent, and transparent accounting of conservation actions and the intended and actual outcomes of conservation projects. It enables project staff to adapt their actions responsively to improve strategy effectiveness and achieve greater conservation impact.

A brief summary of the CAP process, with recommended modifications for estuary conservation planning, is provided below:

1. Identify Planning Team: It is essential to involve stakeholders, practitioners, and managers with cross-realm expertise in the planning exercise and promote “uncommon dialogs” among diverse groups (e.g. fishermen and farmers).

2. Define Project Scope and Conservation Targets: Project scope, scale, and conservation “targets” (the ecological characters that will be the focus of the planning process and associated priority-setting) should be explicitly defined at the outset of planning and should include consideration of ecological processes and functions as primary targets.

3. Assess Viability of Conservation Targets: It is important to characterize the current status of key ecological processes and other targets in order to establish conservation baselines, and then to propose thresholds for a “healthy” state. Because estuarine systems are highly complex, it is often difficult to determine appropriate thresholds at project inception, but this step should nevertheless be proposed at the outset and honed through later planning steps.

4. Identify Critical Threats: Planning teams should identify current and likely future impacts on ecological processes and other estuarine targets, as well as the causes of these impacts. These threats are ranked to identify those in need of immediate conservation action and investment.

5. Conduct Situation Analysis: Situation analysis uncovers relationships between the ecological and human conservation contexts of a project area, by illustrating the relationships among targets, threats, opportunities, stakeholders, and other factors shaping ecological health. A cross-realm situation analysis, as proposed here, may reveal potential for dialogue among diverse interests and novel opportunities for working with upstream stakeholders.

6. Develop Strategies and Actions: The planning team should propose measurable strategies and actions for abating cross-realm threats and enhancing ecological health. Teams should consider opportunities for engaging with those working in similar types of estuaries to find shared solutions to common challenges. The larger scale at which land-sea conservation necessarily occurs creates a more challenging context for strategy development; to address this issue we recommend use of results chains (https://miradi.org/). When created interactively by the team, results chains can reveal hidden points of leverage.

7. Establish Measures: In this step, the team decides how to measure results to determine if strategies are working and what adjustments are needed. While quantitative measures are often difficult to articulate early in project implementation, practitioners should strive to do so, and to adjust their measures over time.

across the region. Integrating site-scale conservation actions into a regional conservation vision will help determine what combination of sites delivers the greatest contribution towards regional conservation goals, and what is most important to protect at an individual site in light of those regional goals and anticipated future climate change.

Conservation Targets that Integrate Across Realms

Conservation planning typically starts with the selection of natural communities and species, representing the diversity of biota in the ecosystem, to serve as focal points (or “targets”) for conservation action (Groves et al. 2002). However, planning for conservation of habitats and species across the land-sea interface, such as in estuaries, can be a daunting task because of the complexity and dynamic nature of each of the

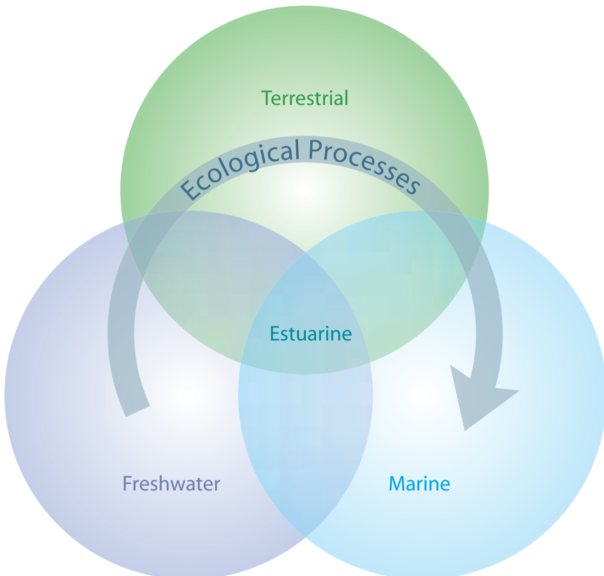


Figure 2-1: Ecological processes within estuaries provide a critical link among realms

realms that meet at the estuary. In these systems, communities and species alone may not be sufficient conservation targets. Ecological processes create and maintain estuarine habitats and integrate across the three realms: marine, terrestrial, and freshwater (**Figure 2-1**). Accordingly, an estuary conservation plan should incorporate ecological processes, functions, and other system-level targets that integrate across realms, in addition to more traditional habitat and species targets.

Four key ecological processes were identified as integrating targets for West Coast estuaries: freshwater input, tidal exchange, sediment regime, and nutrient cycling (**Table 2-1**):

- **Freshwater input:** Freshwater input is an estuary's lifeblood. Freshwater in the watershed drains off of land areas tens to thousands of times larger than the estuary itself, thereby concentrating and integrating the effects of impacts in the watershed. The key attributes of freshwater inflow are quantity (magnitude), temporal pattern (frequency, duration, timing, and rate of change) and quality.

Integrating Targets	Key Attributes of Target	Importance to Estuaries
Freshwater inputs	• Quantity • Quality • Timing	• Advection – transport in water column • Connectivity to upstream water bodies (important for migrating organisms) • Currents and vertical mixing • Distribution of flora and fauna; trophic interactions • Flushing and channel maintenance flows • Input and flux of nutrients and organic material from rivers • Salinity and salinity-mediated processes • Sediment regime • Residence time, transport and dilution of pollutants
Tidal exchange	• Tidal influence/prism • Tidal range (depth and latitude)	• Connectivity with ocean – lateral connectivity • Distribution of flora and fauna; trophic interactions • Nutrient fluxes • Primary productivity • Salinity variation and saltwater wedge • Tidal flushing and channel openings • Turbidity
Sediment regime	• Suspended sediment quantity and distribution • Deposited sediment quantity and distribution	• Distribution of flora and fauna; trophic interactions • Creates habitat and builds or maintains elevation (deposition); vegetation structure • Nutrient and oxygen fluxes • Primary productivity • Turbidity • Transport and accumulation of pollutants
Nutrient cycling	• Dissolved organic/inorganic matter • Particulate organic/inorganic matter	• Denitrification and venting of N_2 gas • Export of nitrogen to marine environment • Primary productivity • Distribution of flora and fauna; trophic interactions • Uptake of nitrogen by seagrasses and phytoplankton

Table 2-1: Key estuarine processes

- **Tidal exchange:** Local patterns of waves, currents, and tidal exchange control the volume of water moving into and out of an estuary during the tidal cycle. Just as freshwater flow carries terrestrial nutrients and materials into the estuary, tidal exchange provides a connection between the marine environment and the estuary. Carbon and nutrient flux in both directions—between land and sea—fuels primary production, which in turn influences species composition and density. Tidal exchange influences turbidity and the location of the saltwater wedge, which plays a major role in determining the distribution of communities of plants, animals, and microorganisms within the estuary. Tidal flushing is also important for moving nutrient and contaminant loads out of the estuary (Moss et al. 2006; Hansen 2008; Hansen et al. 2008).
- **Sediment regime:** Sediment enters the estuary from the watershed via freshwater inflows and from the marine environment via tidal forces. Deposited sediments create habitat and build and stabilize intertidal wetlands, banks, and shoals; maintain marsh elevation; supply nutrients; and buffer coastal erosion. Suspended sediments influence the light regime of the estuary and food supply (Thrush et al. 2004).
- **Nutrient dynamics:** Nutrients are transported to estuaries from catchment, atmospheric, and oceanic sources as both dissolved and particulate matter. The cycling of two nutrients, nitrogen and phosphorus, is especially important in estuaries. Nutrient-rich freshwater from the catchment mixes with highly oxygenated waters from the ocean, making estuaries the most biologically productive regions of the marine environment. Coastal upwelling plays an important role in nutrient transport into some estuaries. Nutrients are exchanged upstream and downstream through water and animal movement and microbes recycle nutrients and exchange nitrogen with the atmosphere (Dennison and Abal 1999; Pennifold and Davis 2001; Peirson et al. 2002; Sheaves et al. 2006).

The nutrient-rich waters of estuaries and associated wetlands create a highly productive environment for plants and animals and provide for a variety of ecosystem functions. Four key estuarine functions were identified as potential integrating targets (**Table 2-2**):

Integrating Targets	Key Attributes of Target	Importance to Estuaries
Nursery habitat for juvenile fish (e.g., anadromous fish, pelagic fish, groundfish) and invertebrates (e.g., crabs, shellfish)	• Abundance and quality of nursery habitat (with increased growth and survival of juveniles and production of adult recruits relative to other non-nursery habitat) • Presence of ecosystem engineers (e.g., submerged aquatic vegetation, coastal wetlands)	• Population viability of key species: abundance, growth, survival of juvenile stages • Trophic interactions • Export of biota/energy to coastal systems • Connectivity of realms
Migratory pathways (e.g., for diadromous fish such as salmonids, smelt, lamprey, sturgeon) or migratory stopovers (for migratory waterfowl, shorebirds, marine mammals)	• Unimpeded migratory corridors (no barriers to migration or stopover) • Abundance and quality of resting and feeding habitats for migrating species	• Population viability of key species (abundance, growth, survival of migratory stages) • Connectivity of realms • Trophic interactions • Nutrient dynamics
Resting, breeding, rearing, or feeding areas (e.g., for waterfowl, shorebirds, fish, marine mammals)	• Abundance and quality of habitats suitable for resting, rearing and feeding (e.g., mudflats, eelgrass, shorelines with little human disturbance, etc.)	• Population viability of key species • Connectivity of realms • Trophic interactions • Nutrient dynamics

Table 2-2: Key estuarine functions

TEXT BOX 4: NURSERY ROLE OF WEST COAST ESTUARIES FOR SELECTED SPECIES

Estuaries are widely recognized as important nursery grounds for juvenile stages of many marine and anadromous fish and invertebrate species (Yoklavich et al. 1991; Beck et al. 2001; Gillanders et al. 2003; Brown 2006). Estuarine habitats can be defined as performing a “nursery function” if juveniles appear more frequently, grow more quickly, and survive better than in other coastal habitats (Beck et al. 2001). West Coast estuaries play an important nursery role for many species of commercial and recreational importance, including Dungeness crab, salmonids, and a variety of flatfish species (Monaco et al 1990; Armstrong et al. 2003; Brown 2006). Dungeness crabs spends their juvenile (post-larval) stage within estuaries and then migrate seaward to coastal waters as they mature; adult male crabs support an commercial fishery that was valued in 2009 at almost $122 million (Armstrong et al. 2003; PacFIN 2010). Chemical and trace elements within otoliths of juvenile flatfish have been used as a way to determine individuals’ estuary of origin; this technique may show which estuaries are more important for juvenile flatfish (Forrester and Swearer 2002; Brown 2006; Fodrie and Levin 2008).

Unfortunately, relatively little is known about the specific role of most West Coast estuaries as nursery habitat for species of biodiversity or commercial significance. A database was assembled of documented presence of juvenile stages in West Coast estuaries, based on literature reviews, for 12 selected species (**See table 1**). Information was found for some of those species in 101 out of 146 estuaries. More information was available from the larger and better studied estuaries like San Francisco Bay, Columbia River, Rogue River, Elkhorn Slough, and Puget Sound. There is clearly a need for a more focused scientific assessment of which West Coast estuaries are the most important providers of this valuable nursery function, and which habitats within those estuarine ecosystems are most critical for each species of interest.

Table 1: Number of West Coast Estuaries with documented presence of juveniles of selected species

Species	Geographic Range (Emmett et al. 1991)	Number of estuaries with documented presence of juveniles
Dungeness crab (*Cancer magister*)	Santa Barbara, California to Pribilof Islands (southeastern Bering Sea)	37
Coho salmon (*Oncorhynchus kisutch*)	Monterey Bay, California to Point Hope, Alaska	41
Pink salmon (*Oncorhynchus gorbuscha*)	Russian River, California to northern Alaska	7
Chum salmon (*Oncorhynchus keta*)	San Lorenzo River, California to Arctic shore of Alaska	22
Chinook salmon (*Oncorhynchus tshawytscha*)	San Francisco Bay, California to northern Alaska	34
Steelhead (*Oncorhynchus mykiss*)	Ventura River, California to Kuskokwim River, Alaska	41
Pacific herring (*Clupea pallasi*)	Ensenada, Baja California to northern Alaska	34
English sole (*Pleuronectes vetulus*)	Central Baja California to Unimak Island, Alaska	39
California halibut (*Paralichthys californicus*)	Magdalena Bay, Baja California to Quillayute River, Washington	27
Starry flounder (*Platichthys stellatus*)	Santa Ynez River, California to Bering Sea	31
White sturgeon (*Acipenser transmontanus*)	Ensenada, Mexico to Cook Inlet (northwestern Alaska)	18
Green sturgeon (*Acipenser medirostris*)	Ensenada, Mexico to southeast Alaska	15

- **Nursery habitat for juvenile marine fish and invertebrates:** estuaries provide nursery habitat for the juvenile forms of some marine fish and invertebrate species that in turn provide food for other levels of the food chain, including shore birds, waterfowl, larger fish, and marine mammals. Significantly, West Coast estuaries provide critical nursery habitat for many commercially important species such as flatfish, Dungeness crab, and salmonids (Beck et al. 2001; Monaco et al. 1990; Monaco et al. 1992; Brown 2006); however, limited information is available for West Coast estuaries (**Text Box 4**).
- **Migratory pathways for anadromous fish:** Estuaries also serve as migration corridors to and from spawning and rearing grounds for various Pacific anadromous species, including salmonids, lampreys, and sturgeons. Some species may spend only days in estuarine habitats, while others reside in estuaries for months at a time before ocean or freshwater entry (Thorpe 1994; Aitkin 1998; Bottom et al. 2005; Bond et al. 2008).
- **Resting, rearing, or feeding areas for migratory birds:** Many waterfowl and shorebirds utilize the open waters, marshes, and mudflats of estuaries for resting, rearing, or feeding areas. In addition, the riparian corridors along creeks and rivers that enter into estuaries are important habitats for songbirds and other species. Sixty-five percent of estuaries in the region include an Audubon-designated Important Bird Area (IBA) (**Figure 2-2a**). In southern California, almost every estuary has an IBA, highlighting the role of these estuaries as important patches of biodiversity in a very fragmented landscape.
- **Resting, rearing, or feeding areas for marine mammals:** Many harbor seals, sea lions and sea otters use estuarine areas (calm waters, mudflats, beaches) to haul out and rest and some species feed on invertebrates and fish within estuaries. Dolphins, porpoises, and small whales spend time resting or feeding in deeper waters of estuaries.

Additional habitat or species-level conservation targets should also be incorporated if ecological processes and functions are inadequate as proxies for biodiversity in a particular estuary. West Coast estuaries vary significantly in vegetation and wildlife habitat composition and their contribution to regional biodiversity. Species richness, defined as the number of species in a given area, is not well characterized and available data are biased toward well-studied sites and threatened and endangered species. However, these data show concentrations of species occurrences in southern California and San Francisco Bay and the larger estuaries in Oregon and Washington (**Figure 2-2b**). In complex estuaries with freshwater, riparian, wetland, and open water habitats, habitats and species are also important conservation targets to include. Emphasis should be placed on those conservation targets that also integrate across realms such as:

- **Floodplain habitats:** In areas where underlying geology and hydrology promote formation of an unconstricted valley or lowland, and the ecological processes shaping these areas are largely intact, there are usually diverse "floodplain habitats." Well-developed, intact floodplains are biologically rich because of the structurally complex array of habitats supported in broad lowlands, typically including salt, fresh, and brackish-water wetland types, riparian forests, wet meadows, grasslands, shrublands, dunes, dune lakes and ponds, beach, and open-water habitats. These areas provide habitat for numerous species when compared to narrow, truncated, and hence less complex estuarine environments such as steep-sided river mouth estuaries. **Figure 2-2c** illustrates the distribution of natural land cover within the Federal Emergency Management Agency's (FEMA) Q-3, 100-, and 500-year floodplains.[4] A large amount of floodplain habitat has been converted to urban and agriculture land cover, so the current distribution of this habitat type is a fraction of the historical distribution. Nevertheless, San Francisco Bay has more than 227,000 acres of floodplain in its catchments.
- **Freshwater and brackish wetlands and coastal salt marsh:** Vegetated tidal wetlands contain a wide variety of plant and animal species whose distribution depends primarily on tidal elevation and salinity. There are roughly 700,000 acres of salt marshes, brackish marshes, and freshwater marshes in West Coast estuaries (**Figure 2-2d**), although this is only a fraction of the original wetland acreage in these areas. The estuaries with the largest amount of remaining wetland habitats are San Francisco Bay, Puget Sound, and Coos Bay (Oregon).
- **Native oyster beds:** The native Olympia oyster (*Ostrea lurida*) historically formed extensive beds along the West Coast. These oyster beds were the focus of intense harvest through the late 1800s and early 1900s. As harvests declined the intertidal areas were extensively manipulated and oysters were translocated around the coast (particularly from Washington south to San Francisco Bay) to support the industry. The native oyster harvest collapsed and very few beds of native oysters remain today. In most bays on the West Coast, they are functionally extinct, though remnant populations are still found (Kirby 2004; Beck et al. 2009).
- **Anadromous and semi-anadromous fish (salmonids, lamprey, sturgeon):** Pacific salmon species utilize estuaries as rearing habitats and migration corridors to and from natal streams, but the residence time spent in estuaries—and the benefits gained from estuarine residence—vary among species and basins (Thorpe 1994; Aitkin 1998; Bottom et al.

[4] See http://www.fema.gov/plan/prevent/floodplain/nfipkeywords/flood_zones.shtm.

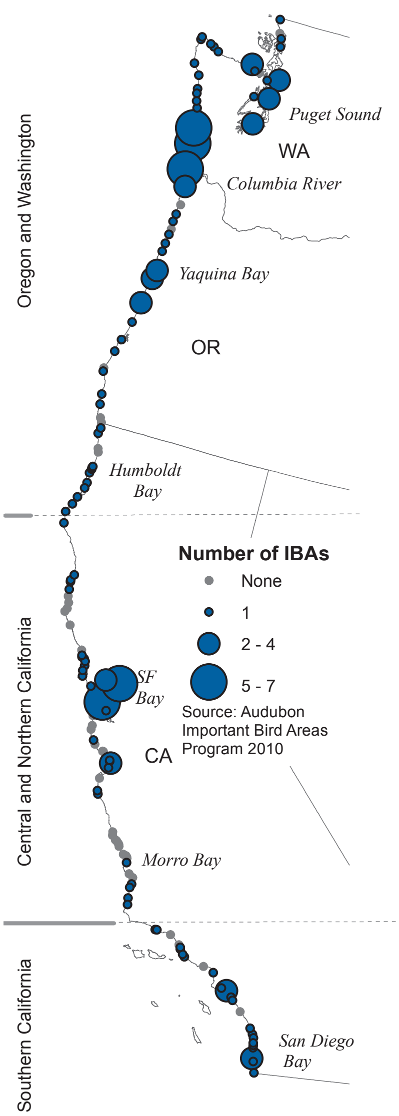


Figure 2-2: Elements of biodiversity in West Coast estuaries - (a) Important Bird Areas

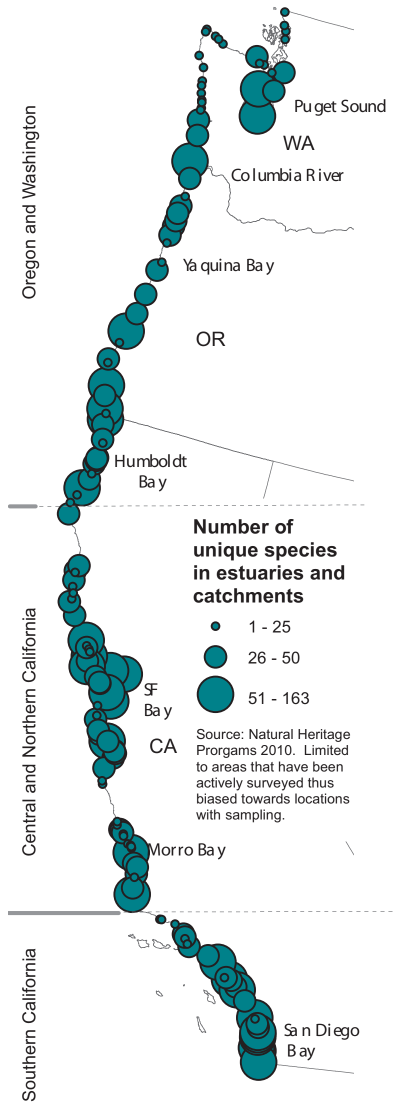


Figure 2-2 (b): Species richness

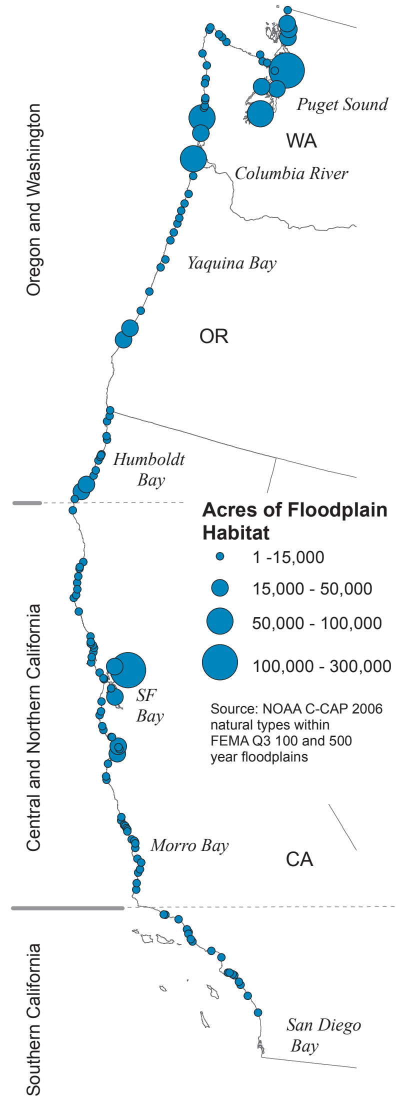


Figure 2-2 (c): Floodplain habitat

2005b; Bond et al. 2008). Within a given salmon run, there may be specific salmon life histories that spend considerably more time in an estuary than others, diversifying salmon life history strategies within the run. Stronghold populations of salmonids have been identified based on population viability, percent natural spawners, and life history diversity (**Text Box 5**). The Columbia River, Rogue River, Klamath River, and San Francisco Bay-Suisun Bay estuaries rank the highest in numbers of stronghold populations (**Figure 2-2e**).

Key Threats to West Coast Estuaries

Estuaries face a broad array of threats, from a variety of sources, that can destroy, degrade, or impair biodiversity, estuarine functions, and ecosystem service values. Alteration of ecological processes beyond their natural range of variation can occur in any one or multiple realms from a variety of sources; alterations to ecological processes in one realm will often impact other realms.

The CAP method for evaluating and ranking the integrity of conservation targets (e.g., ecological processes, functions, and habitats) includes an

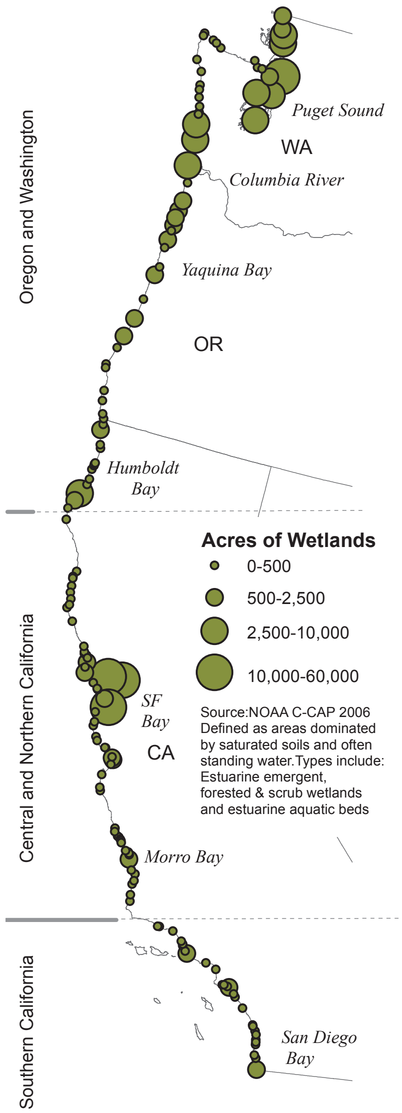


Figure 2-2 (d): Wetland habitat

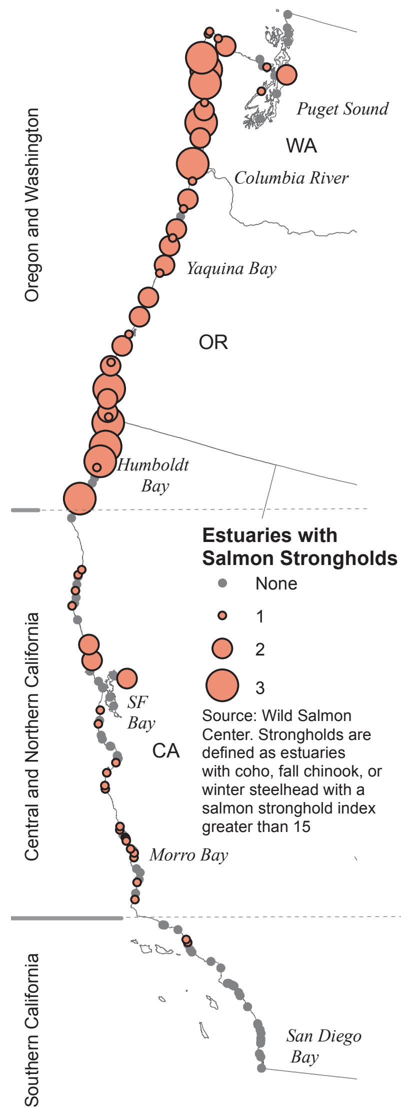


Figure 2-2 (e): Salmon Strongholds

assessment of the viability of the conservation targets and an analysis of threats to that viability. Threats are best described by the type of stressor on a natural system, the source of that stress, and the impact on target viability (Low 2000). There are a broad array of key stressors, sources of stress, and impacts to estuarine ecosystems (**Table 2-3**). For example, freshwater input is one of the ecological process targets with key attributes of quantity, quality, and timing of freshwater inputs into the estuary (**Table 2-1**). Stresses on these key attributes include decreased or increased flow, reduced water quality, and alteration of flow timing. These stresses can affect both physical (currents and vertical mixing, connectivity, dissolved oxygen, etc.) and biological components (primary productivity, freshwater habitat, etc.). For example, reduced flow during salmon spawning can affect the quantity and quality of fish habitat in the estuary, limit the migration and access to suitable spawning habitat upstream, and increase water temperatures to a range unsuitable for migrating fish. Sources of these reduced flows can include diversions and dams, groundwater use, land use, and climate change.

TEXT BOX 5: THE IMPORTANCE OF ESTUARIES FOR PACIFIC SALMONIDS

Run	Stronghold populations	Total populations	Percentage Strong	Number of estuaries with stronghold populations
Chum	22	78	28%	8
Coho	47	255	18%	24
Chinook	74	351	21%	35
Pink	6	14	43%	3
Steelhead	118	482	24%	54
Sockeye	0	7	0%	0
Total	267	1187	22%	124

Table 1. Salmon stronghold runs and populations

Estuaries serve three main functions for salmonids in their life cycle: 1) a productive foraging area where growth can take place prior to ocean entry, 2) a transitional zone where physiological adaptations occur from freshwater to saltwater and back again, and 3) a temporary refuge area for juveniles from marine predators (Bottom et al. 2005b; Aitkin 1998; Bond et al. 2008; Fresh 2006). Pacific salmonids may be present in estuaries during all seasons because of the complex and varied life history strategies that have evolved across species and basins (Bottom et al. 2005b). Stream-type fish that spend a year or more rearing in freshwater before migrating to the ocean typically move through estuaries rapidly, spending little time feeding or acclimating to the salinity (Aitkin 1998; Bottom et al. 2005b), while finding refuge from predators within productive estuary habitats (Bottom et al. 2005b). Ocean-type Chinook salmon and California steelhead populations tend to depend upon estuarine habitats most heavily, adapting to saltwater and foraging and growing within estuaries for months at a time (Bottom et al. 2005a; Bond et al. 2008; Hayes et al. 2008). Although most coho salmon rear for at least a year in freshwater and pass quickly through estuaries, a separate life history strategy exists for fish known as "nomads," which find refuge in estuaries for longer periods of time (Thorpe 1994; Aitkin 1998; Koski 2009). Sockeye salmon typically rear as juveniles in freshwater lakes before their ocean life stage, but "sea-type" sockeye in the Situk estuary in Alaska migrate to sea as fry and spend longer periods of time both rearing and adapting to the salinity in estuaries (Thorpe 1994).

Salmon populations were assigned to estuaries in this assessment using a spatial database for Pacific salmon populations developed by the Wild Salmon Center. The Wild Salmon Center data identified ten runs[1] of 1,187 salmon populations across the three states, and worked with regional salmon experts and data to develop an index of the strength of each population based on population viability, percent natural spawners, and life history diversity. Because of the geographical extent of this assessment, 201 salmon populations identified by the Wild Salmon Center were not assigned to estuaries included in this assessment. The Wild Salmon Center identified 267 of the 1,187 populations (22 percent) as strongholds (those with high population viability, life history diversity, and percent wild fish) (Table 1). Note that no populations of sockeye or steelhead were considered strong.

Of the 267 stronghold populations, 243 (or 91%) are associated with estuaries included in this assessment. The populations identified as strong are linked to 66 of the 146 estuaries included in this assessment (note that multiple populations can be assigned to individual estuaries.) Figure 1 shows the number of populations considered strong that are associated with estuaries in this study. The Columbia, Rogue, and Klamath Rivers and the San Francisco Bay Estuary rank the highest in numbers of strong populations of multiple species.

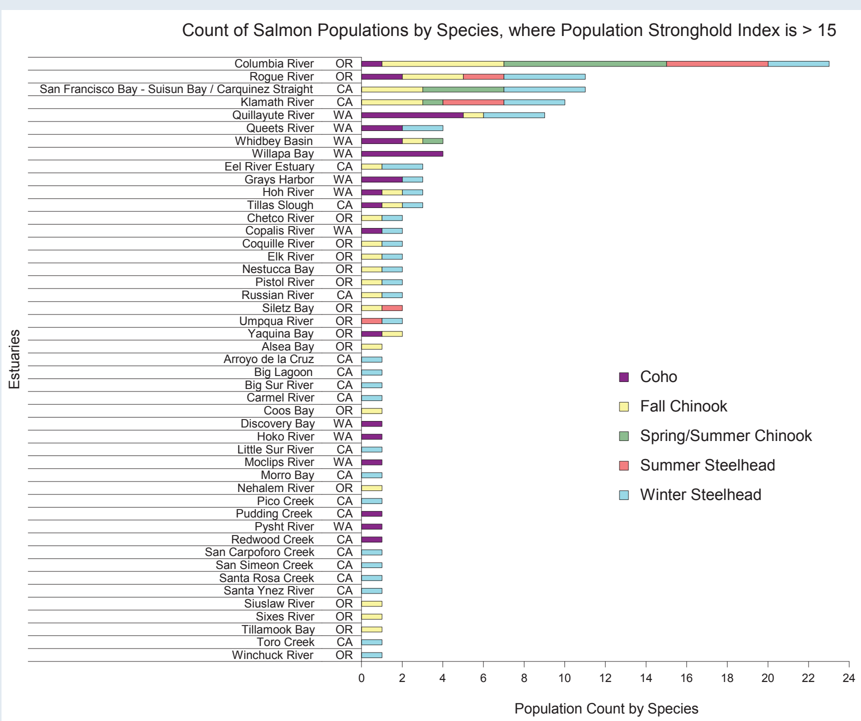


Figure 1: Count of salmon populations by species, where population stronghold index is >15

[1] Chum, coho, fall Chinook, pink, sockeye, spring/summer Chinook, summer steelhead, winter Chinook, winter steelhead

Stress	Primary Source	Impacts
Altered tidal exchange [Key attributes: tidal prism and range]	• Mouth manipulations including jetties, armoring, and dredging	• Salinity range • Connectivity • Flushing • Change or loss of biota • Estuary mouth open/close pattern
Altered nutrient and water quality [Key attributes: dissolved and particulate organic/inorganic matter]	Non-point sources: • Agriculture (row crops, pasture) • Urban/development Point sources: • Toxic release sites • Urban/development	• Nutrient dynamics • Contaminants • Trophic structure and dynamics • Population level impacts (mortality, reproduction)
Altered freshwater inputs [Key attributes: quantity, quality and timing of flow]	• Dams • Diversions – groundwater withdrawal • Levees and dikes	• Salinity regime • Flushing flows and channel maintenance • Connectivity • Biodiversity habitat heterogeneity • Currents and vertical mixing • Nutrient flux • River-supplied nutrients and organic matter • Change or loss of biota
Altered sediment regime – Increased sediment [Key attributes: suspended and deposited sediment – quantity and distribution]	• Forestry • Agriculture	• Causes premature infilling of estuary • Connectivity – mouth and delta • Smothers flora and fauna • Increased turbidity – light environment • Trophic structure and dynamics
Altered sediment regime – Decreased sediment [Key attributes: suspended and deposited sediment – quantity and distribution]	• Dams/barriers • Impervious surfaces	• Habitat loss and inability to keep up with sea level rise • Decreased turbidity • Loss of nutrients • Trophic structure and dynamics
Climate Change	Global emissions causing: • Sea level rise • Increased storms and erosion • Acidification • Changes in upwelling	• Drowns habitat • Causes human responses such as armoring • Loss of shellfish • Altered nutrient dynamics
Invasive species	• Ballast water	• Trophic structure and dynamics

Table 2-3: Stresses, sources of stress, and impacts to estuaries

Figure 2-3 illustrates how targets, stresses, and threats are linked and where strategies can then be developed to abate the critical threats identified (*See* Miradi software for tool to build situation diagrams and results chains: https://miradi.org/). Critical threats to West Coast estuarine ecosystems include:

Altered tidal exchange: Man-made structures such as jetties, dikes, and other barriers alter the natural tidal exchange or flow of seawater through estuaries. Tidal exchange alterations (both restriction and expansion) affect salinity, water quality, temperature, nutrient concentrations, habitat distribution, and abundance of invasive species in estuaries. Tidal

Figure 2-3: Conservation action planning elements in identifying strategies to abate threats to focal conservation targets

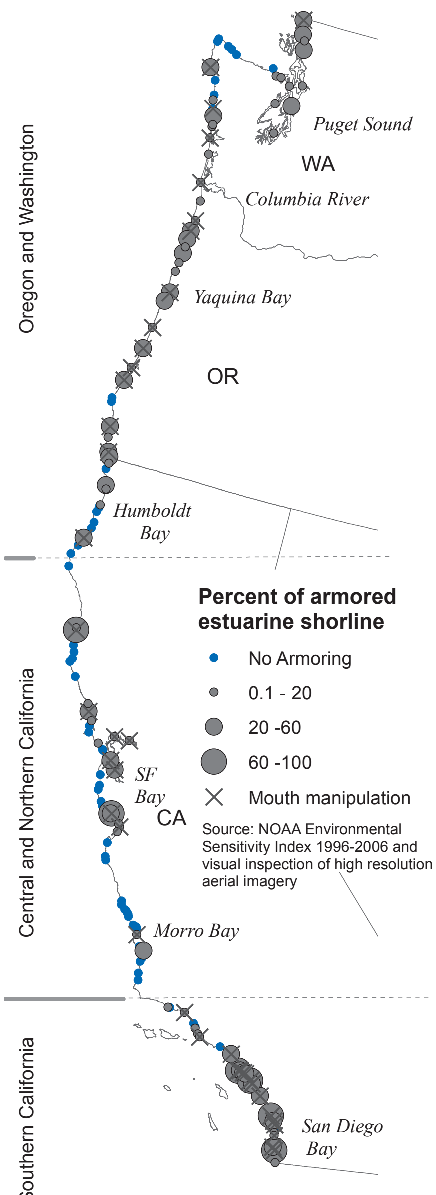


Figure 2-4: Amount of shoreline armoring and locations where estuary mouths are maintained open with jetties or other structures

restriction can result in reduced flushing of nutrients, concentration of pollutants, eutrophication and hypoxic conditions that lead to increased mortality in fishes and other marine organisms. In contrast, exposing a formerly tidally-restricted estuary to open flushing can cause tidal scour and increased salinity (Barrett et al. 2006; Ritter et al. 2008).

Many West Coast estuaries have been subject to shoreline armoring (seawalls, jetties, hardened shorelines) and mouth manipulation (in which the mouth of an estuary is enlarged or held open with jetties) that alter tidal exchange (**Figure 2-4**). Many southern California estuaries have a high degree of armoring for port, marina, and urban development. Even some small river mouth estuaries (e.g., Noyo Harbor, California) are heavily armored to maintain fishing harbor facilities. At least 40 estuaries along the coast have their mouths manipulated to reduce or enhance exchange with the ocean.

Dike and levee systems have also altered the way in which tide and river meet in estuaries. These systems were often built to convert wetlands to other uses, such as agriculture or development. By substantially reducing the area flooded by the incoming tide, the hydraulic force of tidal water is reduced, leading to increased sedimentation and substantial loss of tidal channel habitat in the remaining marsh. This has substantial effects on ecological processes such as nutrient and organic matter exchange, as well as access by fish, birds and other wildlife. Dikes and levees also affect freshwater and sediment routing by constraining flows in channels, effectively creating a “pinched hose” effect. Rather than slowing down and spreading out in the estuary as it meets the tide, the constricted water carries greater energy, propelling freshwater, sediment, and other materials more swiftly past remnant tidal marshes and into the deeper waters of receiving bays. The result is greater salinity penetration into peripheral tidal marshes, reduced accretion rates, lower marsh productivity, and lower water quality in receiving bays, along with smothered eelgrass beds.

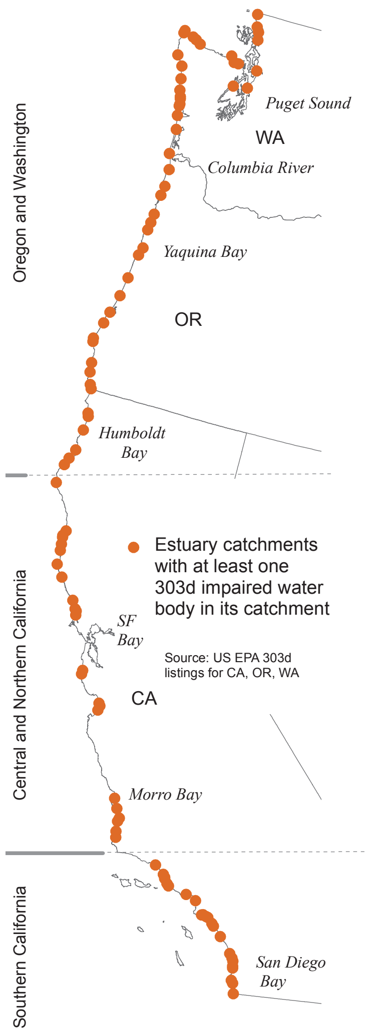


Figure 2-5: Distribution of estuaries with 303(d)-listed impaired waterbodies - (a) all estuaries with impaired water bodiess

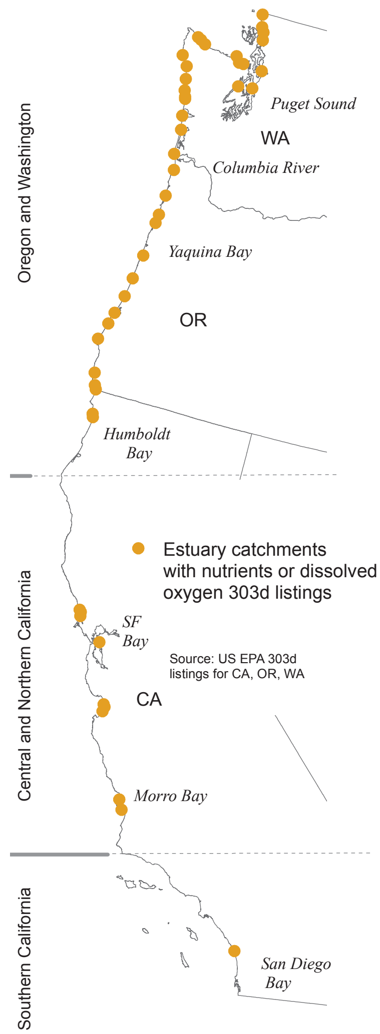


Figure 2-5 (b): sediment and temperature impaired waterbodies.

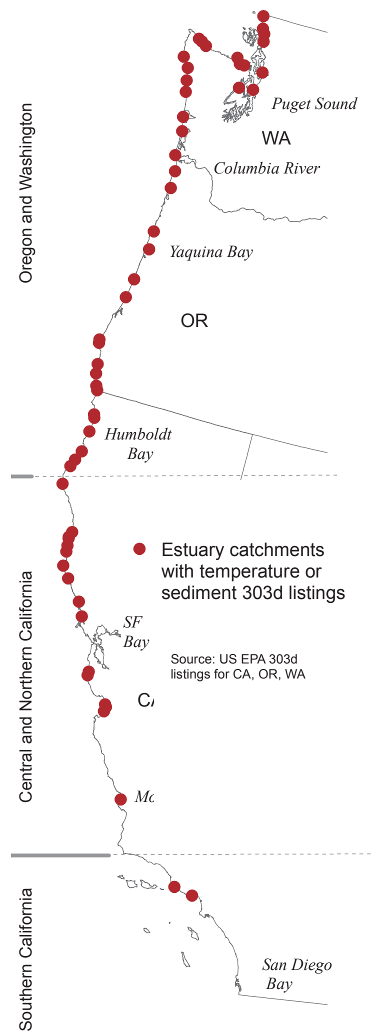


Figure 2-5 (c): nutrient and dissolved oxygen impaired waterbodies.

Altered nutrient and water quality: Non-point sources, such as agricultural runoff of fertilizers and urban runoff from impermeable surfaces like roads, can increase nutrients and affect water quality by adding nitrogen, phosphorus, trace metals, and hydrocarbons to estuarine systems. Point sources such as sewer outfalls and industrial drains can add excess organic and inorganic contamination. Both point and non-point sources can lead to eutrophication, hypoxia, disease, and dangerous levels of contaminants (Nichols et al. 1986; Moss et al. 2006; EPA 2009).

Altered nutrient dynamics and water quality are evident throughout the region, as illustrated by the distribution of impaired water bodies designated under the Clean Water Act. One hundred estuaries have at least one waterway listed as impaired on the EPA's 303(d) list (**Figure 2-5a-c**).

Waterways of 45 estuary catchments in the study area are listed as impaired for nutrients and low dissolved oxygen, with many additional listings for other runoff-transported pollutants.

Altered freshwater inputs: Freshwater inputs to estuaries are altered when water is withdrawn from lakes, rivers, and groundwater aquifers, and when dams, levees, and other barriers are constructed. These alterations can cause changes in salinity, flushing, and connectivity in estuaries. Too little freshwater input into an estuary may result in higher salinity, reduction in nutrient and sediment inputs, loss of wetland habitat, and less flushing of inorganic and organic materials, while too much freshwater input can have the opposite effects (Copeland 1966; Nichols et al. 1986; Kennish 2002).

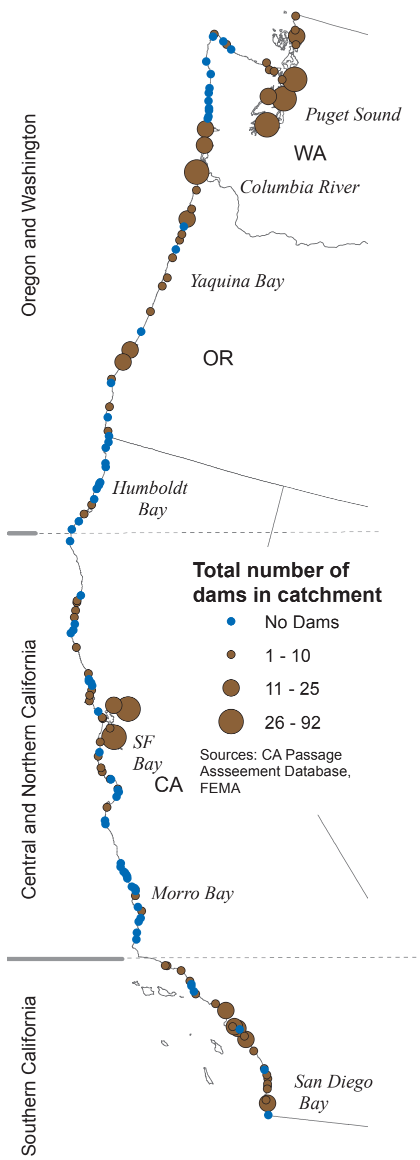


Figure 2-6: Distribution of dams in West Coast estuary catchments

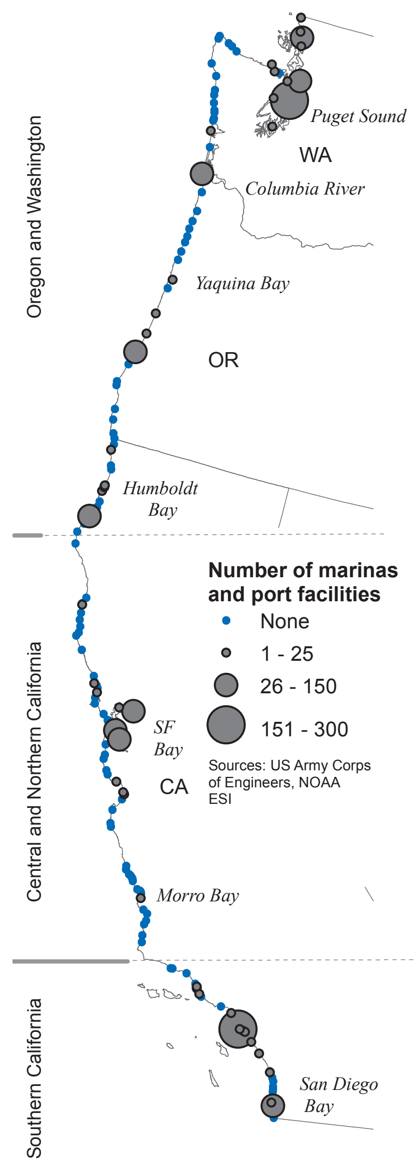


Figure 2-7: Distribution of marinas and port facilities in estuaries

Most West Coast rivers are dammed to provide freshwater for agriculture, industry, and urban development, as well electricity and flood management. **Figure 2-6** illustrates the geographic pattern of dams in the immediately-adjacent catchment of estuaries (note these data do not reflect dams further upstream). Dams immediately adjacent to estuaries tend to be concentrated in the more developed catchments of southern California and urban centers throughout the region.

Altered sediment regime: Increased erosion related to agriculture, forest clearing, and construction of impervious surfaces (roads and development) causes an increase in turbidity, suspended soils, and sedimentation of estuaries (Meade 1982; Thrush et al. 2004). Too much sediment and turbidity can smother vegetation and reduce sunlight for photosynthesis. Suspended sediments can also clog feeding structures for fish and filter feeders. Reductions in sediment supply caused by dams and other barriers in rivers and streams result in habitat impacts and decreased nutrients available for organisms in estuaries (Bednarek 2001). Reduced sediment supply also limits the estuary's ability to maintain its elevation in relation to sea level and leaves estuaries susceptible to salt water intrusion (Ganju and Schoellhamer 2010). A large number of

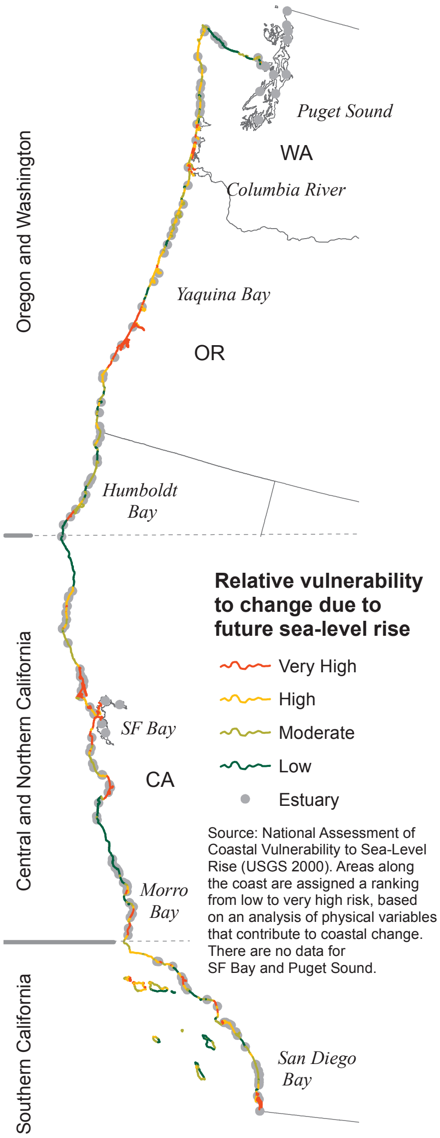


Figure 2-8: Coastal vulnerability to sea level rise

© Dean Sullivan

estuaries on the West Coast have river inputs that are designated as impaired for sediment and turbidity (**Figure 2-5b**).

Invasive Species: Because of their role as important ports and harbors, estuaries have been subject to the arrival and establishment of many invasive species. Spread of invasive species into estuaries is primarily through ballast water in ships, aquaculture, and recreational and commercial vessels. Once established, invasive species can be very difficult to eradicate (Bax et al. 2003; Marchetti et al. 2004). Invasive species can impact native species (e.g., the invasive snail *Batillaria attramentaria* has displaced the native snail *Cerithidea californica* in central California), whole communities (e.g., the invasive Asian mussel, *Musculista senhousia*, has affected diversity and abundance of native mudflat species in Mission Bay, San Diego), or entire ecosystems (e.g., the Asian clam, *Potamocorbula amurensis*, in San Francisco has disrupted ecosystem structure) (Grosholz 2002; Bax et al. 2003; Grosholz and Ruiz 2009). In California there are hundreds of marine and estuarine invasive species; San Francisco Bay is considered the most invaded aquatic ecosystem in North America (Ray 2005; Cohen and Carlton 1995). Invasive species in West Coast estuaries have generally not been well-mapped and their spread is often documented after the fact.

Direct habitat loss: Direct habitat loss results from land conversion (development, agriculture, etc.), armoring, diking, and infilling in the coastal margins around estuaries. About 50 percent of the original salt marsh habitat in the United States has been lost due to development and land conversion (Kennish 2002) and about 90 percent has been lost in California (Zedler et al 2001). Substantial wetland and floodplain habitat has been lost or altered in West Coast estuaries as a result of urban, agriculture, and port development around the margins of estuaries (**Figure 2-7**) and armoring (**Figure 2-4**). Subtidal habitats have been lost due to aquaculture and port and harbor development. The loss of habitat can reduce connectivity between freshwater and marine realms and isolate biological communities (Thrush et al. 2008). It can also affect migratory corridors for birds, nursery habitat, and estuarine productivity. In addition, ecosystem services like flood protection, water storage, provisioning of seafood, and water quality may be affected by the loss of wetland and riparian habitats (EPA 2009).

Climate change: Global climate change will cause sea level rise, ocean acidification, changes in storm intensity and frequency, and changes in temperature and precipitation that will affect West Cost estuaries (Michener et al. 1997; Short and Neckles 1999; Harley et al. 2006; Callaway et al. 2007; Doney et al. 2009). Ocean acidification, a by-product of global climate change, will impact the development and growth of shelled organisms (e.g., clams, oysters, etc.) in estuaries (Orr et al. 2005; Doney et al. 2009). In addition, sea level rise and increased storm intensity and frequency will affect the physical and biological structure of the estuary as well as impact on nearby human infrastructure (Michener et al. 1997). Increased storm frequency will impact estuaries through erosion and storm surge, especially in low-lying, low-relief coastal areas. An increase in temperature will further affect estuaries by altering the photosynthesis-to-respiration ratio, species composition, and thermal expansion (Short and Neckles 1999; Harley et al. 2006). The projected vulnerability of the coastline to sea level rise, based on the USGS's Coastal Vulnerability Index, is shown in **Figure 2-8**. Wetlands are particularly vulnerable to sea level rise because they will need to migrate landward over time to avoid becoming submerged leading to different strategies for conservation and adaptation that may vary by land cover and ownership patterns in the projected migration area (**Text Box 6**).

TEXT BOX 6: THE POTENTIAL FOR WETLAND MIGRATION AND ADAPTATION TO SEA LEVEL RISE IN CALIFORNIA'S ESTUARIES

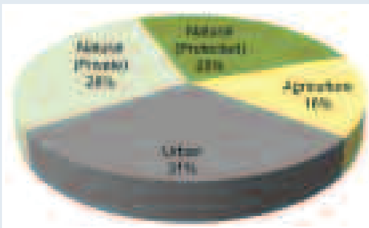


Figure 1: Land cover within the projected sea level rise migration area in 89 California estuaries

In the face of projected sea level rise, coastal natural and human communities will need to adapt. In particular, wetland habitats will need to migrate shoreward as waters rise and the presence of human development or incompatible land uses in the migration zone can be an impediment to wetland migration. In addition, healthy coastal marshes and floodplains can provide "green infrastructure" that can help human communities adapt. We assessed the patterns of land cover and ownership in the projected migration zone for 89 estuaries in California, assuming a 1.4 meter sea level rise over the next 100 years (Hebeger et el.2009).

The approximate total acreage of inundation or wetland migration around those estuaries is 89,000 acres, of which about 59,500 acres, or 67%, is associated with the four sub-basins that constitute San Francisco Bay. About half of that area is in natural land cover, with the remainder split between urban and agriculture (**Figure 1**). Of the 47,500 acres of natural land cover in the wetland migration area, about 47% is already protected or managed by public agencies (e.g., California Department of Fish and Game, U.S. Fish and Wildlife Service, and U.S. Department of Defense).

These data can be shown at the scale of individual estuaries, illustrating how patterns of ownership and land use in the estuary migration area provide a framework for identifying strategies and possible conservation partnerships. **Figure 2** shows land cover in the migration zone at individual estuaries in the Monterey Bay region.

The strategies to facilitate wetland migration will vary depending on the land use and management in the migration zone and can be grouped into four categories:

- **Stewardship**: Estuaries that have large potential wetland migration zones with a high percentage of natural land cover and a high percentage of protected natural land cover are estuaries where strategies to promote good stewardship and sea level rise adaptation on public lands could be employed. Some estuaries that fall into this category are San Pablo Bay, Elkhorn Slough, Mugu Lagoon, Tijuana Slough.
- **Protection**: Estuaries that have large potential wetland migration zones with a high percentage of private natural land cover are estuaries where strategies to acquire conservation easements and fee title could be employed to remove the threat of conversion to agricultural and urban land uses. Some estuaries that fall into this category include San Francisco Bay, Salinas River, and Elkhorn Slough.
- **Agricultural Easements / Agreements**: Estuaries that have large potential wetland migration zones with a high percentage of agriculture are estuaries where strategies to acquire conservation easements and long term agreements could be employed to allow agricultural land to be flooded and restored to wetlands as the sea level rises. Some estuaries that fall into this category include Humboldt Bay, Eel River Estuary, and Watsonville Slough.
- **Green Infrastructure / Wetland Accretion**: Estuaries that have large potential wetland migration zones with a high percentage of urban land are estuaries where strategies to encourage "green" infrastructure (i.e., using the natural landscape for flood control and other infrastructure purposes) rather than "grey" infrastructure (i.e., hardened, engineered) to control floods should be used. In addition, the possibility of encouraging the accretion of sediment in existing wetlands at urban interfaces should be examined to see if they can rise in pace with sea level rise. Estuaries that fall into this category include Central San Francisco Bay and the Santa Ana River estuary.

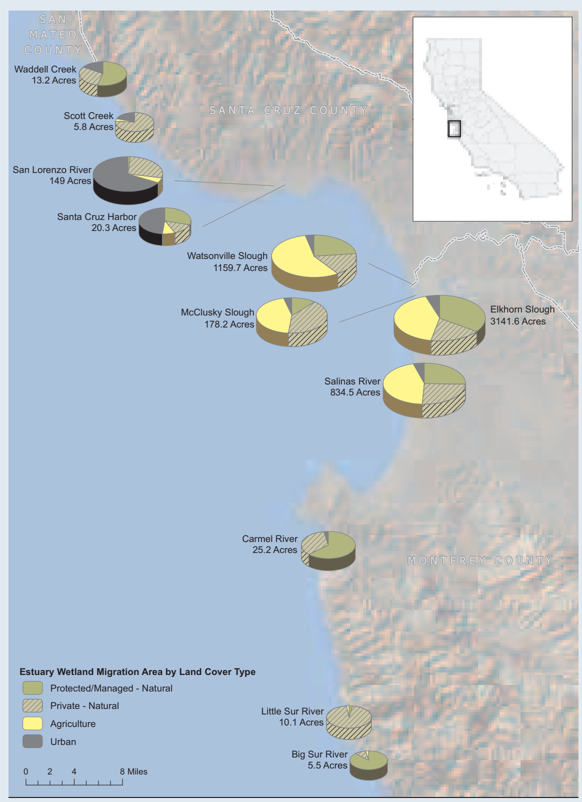
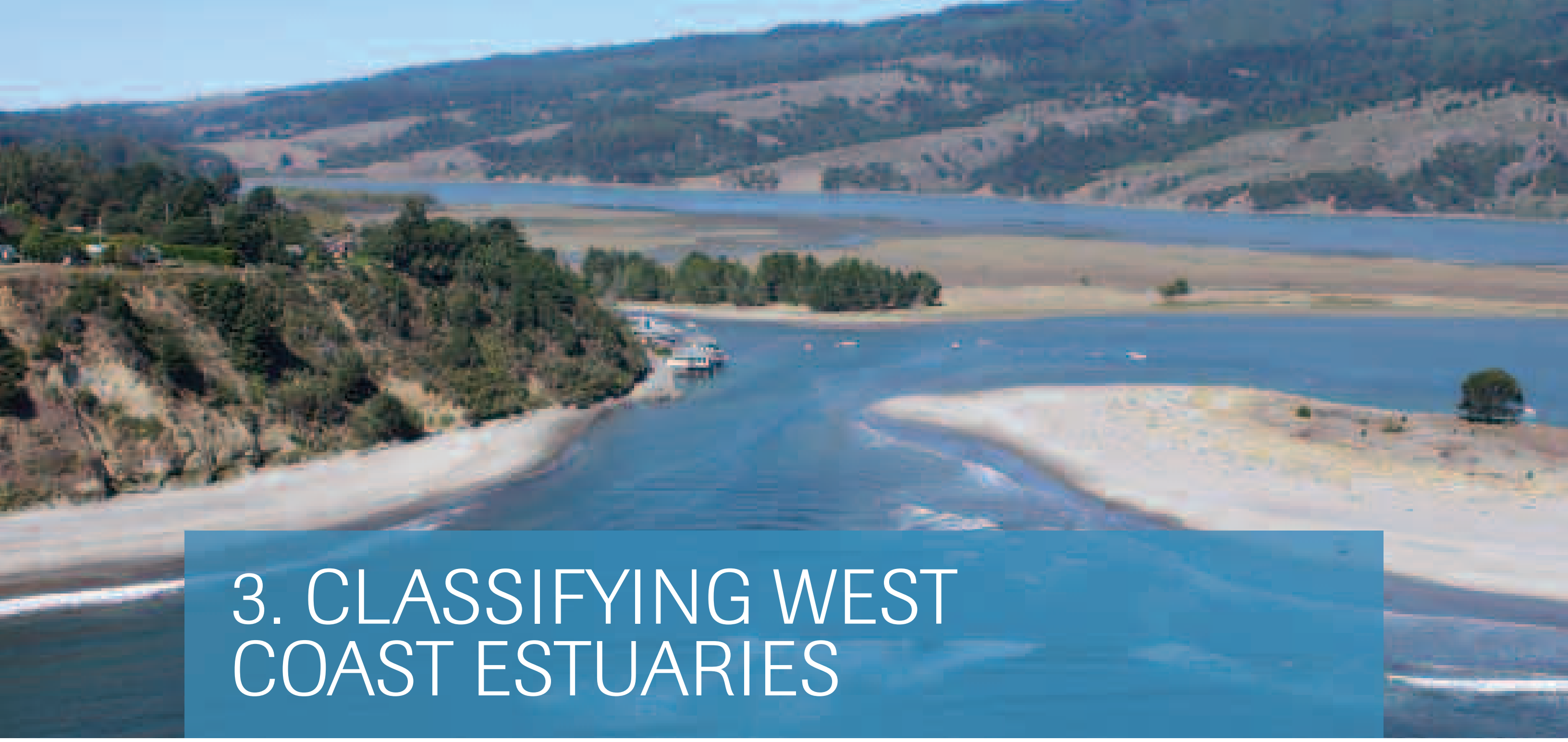


Figure 2: Potential estuary wetland migration area in the Monterey Bay area estuary catchments in response to a 1.4 meter sea-level rise by the year 2100.



3. CLASSIFYING WEST COAST ESTUARIES

© 2002-2010 Kenneth & Gabrielle Adelman

Along the West Coast, there are a diversity of types of estuaries that differ in climatic factors, hydrodynamic processes, connectivity with the coastal ocean, habitats, flora and fauna (Monaco et al. 1992; Emmett et al. 2000; Engle et al. 2007). The conservation of estuarine ecosystems and their associated biodiversity requires recognition of these different types of estuaries for representation in regional conservation plans. The geomorphic shape of estuaries and the physical processes that structure them (tidal exchange, hydrology, sedimentation, etc.) also likely influence their susceptibility to different threats, as well as their ability to recover (Edgar et al. 2000). A classification system that distinguishes among different types of estuaries across the region, and can facilitate the identification of groupings of estuaries based on key factors and processes, should inform conservation and management strategies (Hume et al. 2007; Edgar et al. 2000; Engle et al. 2007).

Hierarchical Classification Approach and Methods

While a variety of classification schemes have been proposed for U.S. estuaries, most are focused only on geomorphology, ecology, physical, or hydrologic factors (Emmet et al. 2000; Engle et al. 2007) and none have been applied to all the West Coast estuaries. Classification schemes based on biological or hydrological information tend to require significant inputs of site-specific data that are often unavailable for every estuary in a region; classification based on geomorphic or geographic patterns alone does not adequately describe important processes that structure the physical and ecological properties of estuaries. Some more comprehensive classification schemes have only been applied to a subset of the estuaries on the West Coast (Ferren et al. 1996).

For this assessment, a hierarchical classification approach was developed that first recognizes regional differences in climate, latitude, and oceanography and then further identifies a typology for individual estuaries based on dominant energy sources and the processes that structure estuaries; a similar approach has been used in Australia (Ryan et al. 2003) and New Zealand (Hume et al. 2007). At the scale of the West Coast, parameters such as latitude, climate, and oceanographic features (such as the California Current) are likely the dominant cause of variation among estuaries. At the scale of individual estuaries, hydrodynamic processes, such as wave energy, tidal energy, and river energy, primarily control estuarine structure (Ryan et al. 2003; Harris et al. 2002; Harris and Heap 2003; Peirson et al. 2002; Hume et al. 2007). This "controlling factor" approach to estuarine typology allows links to be made between physical and ecological processes and potential threats that can alter those processes. Within an estuary type, land use in the catchment is also an important determinant of variation among estuaries. Accordingly, a three-level hierarchical classification of West Coast estuaries was developed using ecoregions, typologies based on hydrodynamic processes, and land cover as a proxy for catchment processes (after Hume et al. 2007).

The hierarchical classification scheme provides an important framework for assessing the representation of estuarine types, and the biodiversity they harbor, in current protected areas or conservation projects. The types of estuaries may also differ in their inherent susceptibility or vulnerability to various threats or human uses in the catchments (Heap et al. 2001; Hume 2007).

Level 1—Ecoregions: At a global scale, estuaries can be classified based on factors such as latitude and climatic and oceanic conditions that affect processes such as solar radiation, heating and cooling, precipitation, and

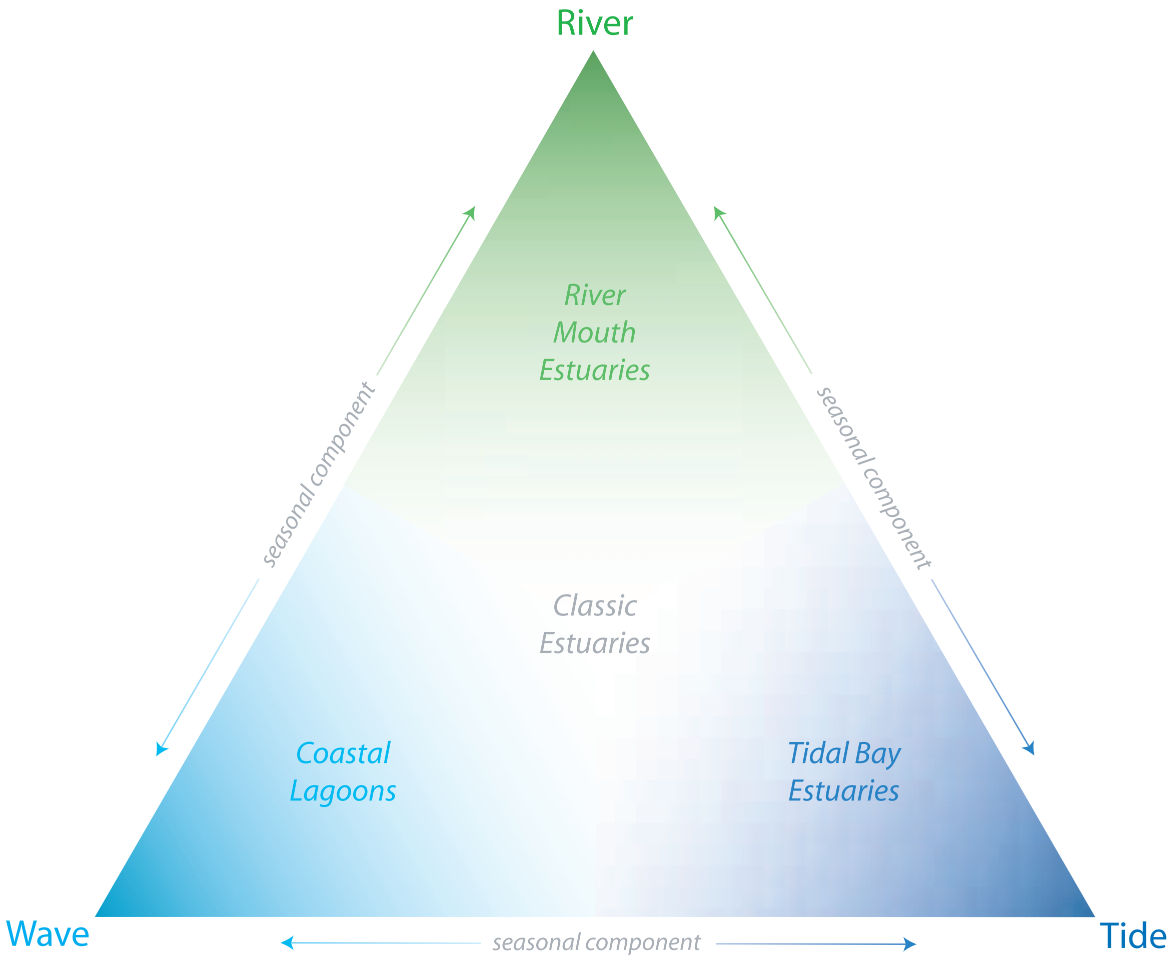


Figure 3-1: Estuarine typology showing relative influence of river, tide, and wave energy

evaporation (Hume et al. 2007). The West Coast, as part of the California Current Large Marine Ecosystem, is characterized by oceanographic and atmospheric conditions that cause upwelling in the summertime of cold, nutrient-rich, deep waters to the surface near shore and along the coast. The degree of influence of the upwelling system, especially inputs of oceanic nutrients into estuaries, varies along the coast and among estuaries. The tidal regime along the West Coast has a mixed semi-diurnal period; however, the tidal fluctuations are the highest in the north (e.g., Puget Sound) and lowest in southern California (Emmet et al. 2000). The West Coast has a range of climatic conditions, with lower temperatures and more precipitation in the north and hotter and drier conditions, with a more Mediterranean climate regime, in the south.

Considering climatic (precipitation), latitude, and marine influences as the most important factors at this scale, Level 1 classes were defined using the large marine ecoregions (Wilkinson et al. 2009) and divided estuaries into three regional groupings: Southern California (Mexico border to Pt. Conception), North-Central California (Pt. Conception to Cape Mendocino), and Oregon and Washington (which also includes part of California north or Cape Mendocino).

Level 2—Estuarine Typology: The Level 2 classification places estuaries into a typology based on factors such as basin morphometry, oceanic forcing, and river forcing that control hydrodynamic processes such as mixing, circulation, stratification, sedimentation, and flushing (Ryan et al. 2003; Hume et al. 2007). Hydrodynamic processes are determined by the interaction of tides and ocean swell, freshwater inflow from rivers, and the wind acting on surface waters. The shape of the basin (e.g., openness of the estuary mouth) and amount of freshwater inflows determines water circulation, mixing, flushing, and sedimentation that affect the physical characteristics of estuaries such as salinity, turbidity, geomorphic features, habitats (intertidal, channels), and stratification (Hume et al. 2007).

Four main estuary types were identified for the West Coast based on a similar approach used in Australia (www.ozcoast.org) of distinguishing estuarine types by the degree of influence of three controlling factors: river, wave, and tidal energy (**Figure 3-1**).

Figure 3-2. Estuarine typology based on relative influence of wave, tidal, and riverine energy.

Each of the 146 estuaries on the West Coast was assigned to one of the four estuarine types as determined by visual inspection of the morphology of the estuary using aerial imagery from a variety of dates and seasons (**Figure 3-2**). The four types include:

Coastal Lagoons. Coastal lagoons are dominated by wave energy, although they can also be tidally influenced when their mouths are open and may have some small riverine inputs. Lagoons are shallow basins that form along high-wave-energy coasts, where low-inflow estuaries are separated from the sea by a wave-built sand barrier. With small watersheds and/or low net precipitation, freshwater inflow is retained in the closed basin. During wet periods, water levels rise and the lagoon may overflow the barrier at its mouth; or, in the event of large storms, the barrier can be breached and the lagoon will become tidal. Due to low river inflow there is no alluvial floodplain or bay-head delta and the system is primarily bounded by intertidal environments. Turbidity is generally low; however, the shallow waters are subject to wind-wave resuspension. Particulate or solute inputs are retained due to very long water residence times; thus these systems are highly susceptible to overloading of nutrients or contaminants. Morphological evolution of lagoons (e.g., infilling) is slow due to a lack of sediment input. The habitats and species that are supported are dominated by estuarine or euryhaline types that can tolerate the chemical conditions and highly variable salinity.

River Mouth estuaries: River mouth estuaries are dominated by river energy, though they can also be influenced by waves and tides and may have wave-built features at their mouths. River-mouth estuaries have limited intertidal volume, short water residence times, shallow water depth and limited stratification. While river mouth estuaries generally receive perennial river flow, producing year-round brackish conditions, flow can vary significantly by season, especially in California. In winter, flow can be high enough to expel all marine and brackish waters from the estuary, while in summer it can be low enough that the mouth is temporarily closed by wave-deposited sediments and the estuary takes on characteristics of a lagoon with brackish surface waters and higher levels of stratification. Turbidity in river mouth estuaries is typically low but variable, depending on catchment characteristics. Sediments and associated pollutants generally move through the estuary and are expelled to coastal waters, and there is little in-estuary processing or trapping of nutrients, except during low-flow periods. River mouth estuaries can be broad and alluvial in nature with extensive marsh habitats or more sharply incised with steep slopes near their mouths (drowned river valleys or canyons). River-mouth estuaries support euryhaline estuarine species, as well as transient marine visitors. Intertidal and subtidal habitats vary depending on the degree of tidal influence. High energy sandy beaches and sandy channels are usually present and subtidal areas may support seagrasses.

Tidal Bay Estuaries: Tidal bay estuaries are deeper-water features that are dominated by tidal energy, although they may have riverine inputs and wave-built features at their mouths. Tidal bay estuaries are reliably open, with deep and often wide entrance channels. The mouth is typically sheltered from waves and the tidal area of the estuary is large, accounting for a large tidal prism that can easily remove any wave-deposited sediment in the mouth. River flow varies but is typically small relative to tidal flows. Tidal currents are strong in the outer estuary, accounting for deeper waters and coarser sediments. Water residence time, controlled by tidal mixing, is much longer in the inner bay and upper channels where tides are weaker. The level of turbidity and the nature of intertidal habitats are dependent on the local tidal range. Upwelled coastal waters often supply nutrients, with higher nutrient concentrations near the mouth. Infilling by sediments is slow due to a lack of delivery of either terrigenous or marine sediments to the mid-estuary and due to strength of tidal scour in the outer estuary. The morphology of tidal bays is variable, ranging from rounded bays to highly indented bays with convoluted shorelines to narrow, tapered, drowned river valleys. Tidal bays typically have an abundant and diverse biota; habitats are typically marine and estuarine with extensive subtidal environments, seagrasses, and narrow intertidal areas with low-elevation salt marshes.

Classic Estuaries: Classic estuaries are influenced by all three controlling factors (river, tide, wave) and not dominated by a single factor, though the relative influence of each factor may vary among estuaries and may also be strongly seasonal. Classic estuaries are characterized by open mouths and strong tidal currents, as well as significant river inflow and strong estuarine circulation, both of which enhance flushing and reduce retention in the basin. With significant river flow, the head of the estuary is characterized by high hydraulic energy, coarse sediments, and fluvial deposits in fringing marshes. Turbidity is high due to the effects of river or tidal action and may preclude establishment of seagrasses in some cases. Flanking environments, such as intertidal flats and saltmarshes, are extensive and tend to trap terrigenous sediments and pollutants. A diverse range of habitats such as open water, tidal channels, intertidal mudflats, saltmarshes, and salt flats are supported.

While each estuary was assigned to a single type, some estuaries exist along a more dynamic continuum that is influenced strongly by seasonal and inter-annual variation or latitudinal patterns. For example, during the long dry summers in much of California, many river-mouth estuaries transition into a lagoon state, with a closed mouth that can persist for months, and return to river-mouth status with the first winter rains. Following an unusual beach-building wave event, a tidal bay may close and convert to a lagoon.

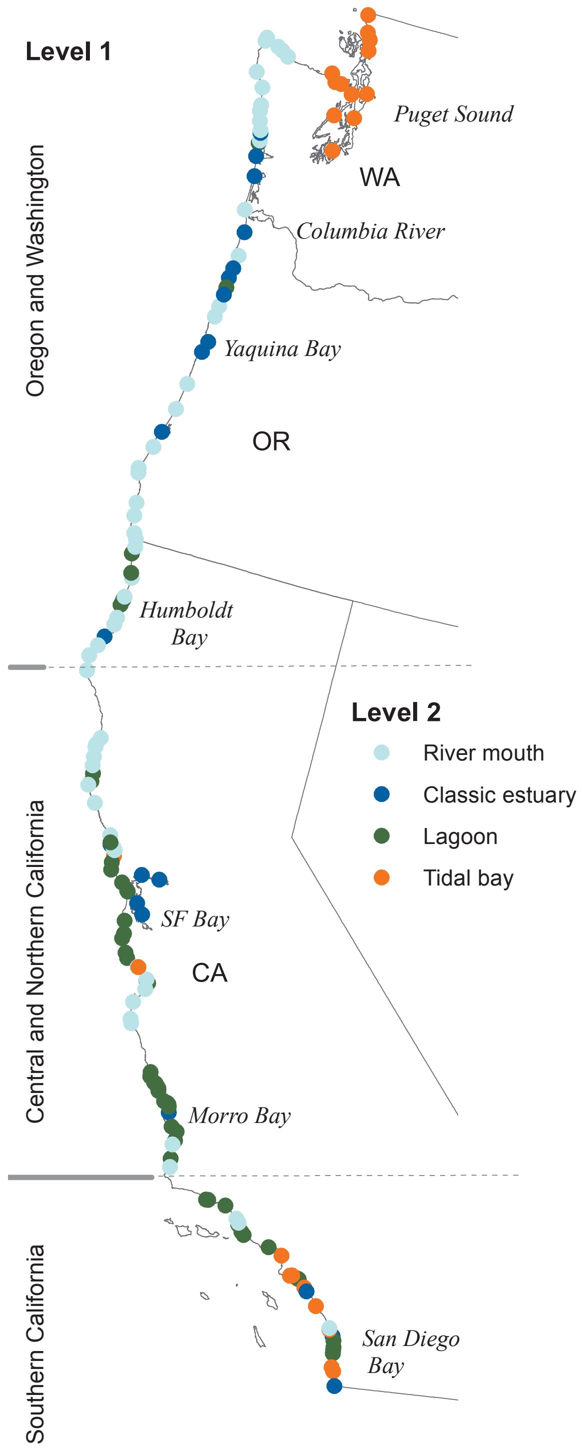


Figure 3-3: Classification of West Coast estuaries showing Level 1 regions and Level 2 types

Level 3: Land Cover in the Catchment: Land cover and geology are subordinate to hydrodynamic processes in determining the character of the whole estuary, but are important determinants of freshwater inflows, erosion

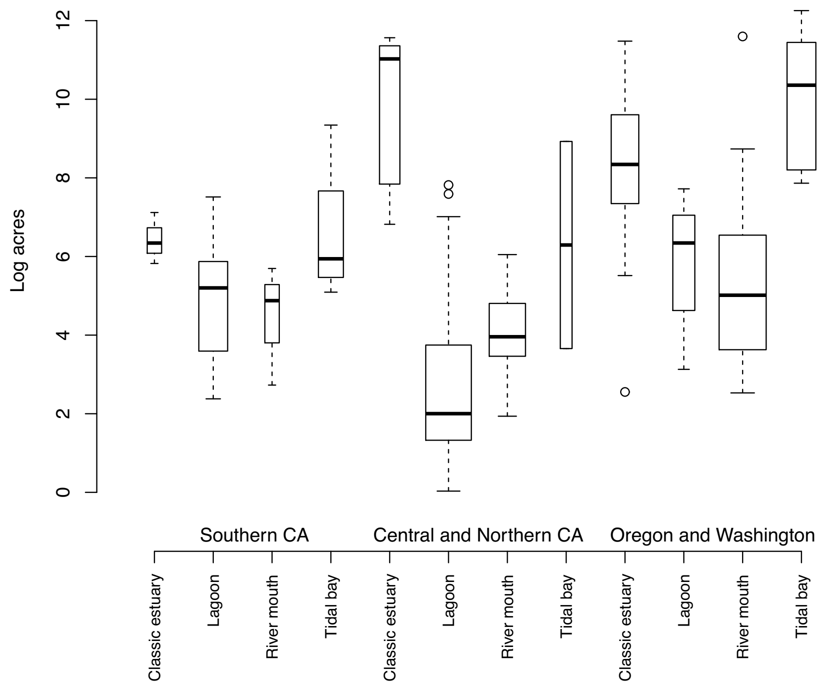


Figure 3-4: Mean size of West Coast estuaries by region and type

rates, and fluxes of terrigenous sediment, nutrients, and other contaminants (Hume et al. 2007). For each estuary, the proportion of each major land cover type (urban, agriculture, forest, scrub, wetland, other) in each estuary catchment was determined using NOAA's Coastal Change and Analysis Program data.

Classification of West Coast Estuaries

All of the estuaries on the West Coast were classified using this hierarchical approach based on their current condition (**Figure 3-3**). Lagoons and river mouth estuaries are more abundant than tidal bay or classic estuaries in the region. Lagoons are a predominant estuary type in southern and central California, while river mouths are more typical further north. A handful of southern California estuaries that have been altered and armored to support port and harbor development were classified as tidal bay estuaries, as they are broadly open to tidal influence and support subtidal habitats, though historically they may have had a different typology. Estuaries in northern California, Oregon, and Washington tend to be larger than central and southern California estuaries, which are predominantly smaller lagoon or river mouth systems (**Figure 3-4**). Tidal bay estuaries and classic estuaries tend to be larger than lagoons and river mouth estuaries throughout the region.

Land cover was used as a proxy for land use and condition of the catchments associated with each estuary in the region (**Table 3-1**). Forests are the predominant land cover type in Washington, Oregon, and northern California. Not surprisingly, urban land cover is highest in southern California and in the San Francisco Bay and Puget Sound catchments.

The four main ecological processes at play in estuaries—freshwater inputs, tidal exchange, sediment dynamics, and nutrient dynamics—are largely controlled by the relative dominance of wave, tide, and river energy, which in turn structure the morphology and ecological function of the estuary. These factors lead to some inherent properties or tendencies of the estuaries—such as residence time, flushing potential, freshwater input, tidal prism, sediment trapping efficiency, and turbidity—that may affect their susceptibility to different threats (**Table 3-2**). Estuary types most vulnerable to increases in nutrient inputs or pollution are those with limited flushing ability and small tidal ranges (i.e., coastal lagoons). River mouth and classic estuaries are expected to be most vulnerable to alterations in freshwater input and manipulations of their mouths that disrupt natural tidal exchange. River mouth estuaries are more susceptible to reductions in freshwater flows because rivers provide the dominant energy source and freshwater flushing is a key property. Coastal lagoons may be more at risk from groundwater pumping, as most of the freshwater inputs to these estuary types come from groundwater. Evaluation of threats for a specific estuary should include consideration of how stressors may be exacerbated or mitigated depending on the type of estuary.

Level 1	Level 2			Level 3						
		n	total acres	Ag	Urban	Forest	Wetland	Scrub & Grass	Open water	Other
Oregon & Washington	Classic estuary	11	210,059	2.2%	2.5%	61.9%	6.0%	19.5%	5.6%	2.5%
	Lagoon	7	5,444	2.8%	5.5%	61.6%	6.2%	14.1%	7.1%	2.7%
	River mouth	32	129,419	2.1%	1.5%	69.2%	4.1%	17.5%	3.2%	2.3%
	Tidal bay	12	726,565	7.5%	16.0%	41.4%	5.3%	9.4%	17.2%	3.2%
Central and Northern California	Classic estuary	6	321,377	8.4%	29.2%	15.1%	5.1%	25.4%	16.5%	0.4%
	Lagoon	30	6,163	6.5%	5.5%	37.5%	1.8%	46.8%	0.9%	0.9%
	River mouth	19	2,041	8.9%	3.5%	56.4%	0.9%	29.7%	0.2%	0.4%
	Tidal bay	2	7,566	1.7%	9.8%	45.9%	1.6%	35.0%	5.6%	0.3%
Southern California	Classic estuary	3	2,141	3.2%	63.1%	1.3%	1.9%	28.5%	1.0%	0.9%
	Lagoon	12	4,870	9.6%	45.3%	7.8%	2.1%	33.6%	0.8%	0.8%
	River mouth	3	444	10.6%	8.6%	21.2%	1.7%	56.7%	0.8%	0.4%
	Tidal bay	9	17,633	0.2%	63.2%	3.0%	1.0%	29.9%	2.2%	0.5%

Table 3-1

Estuary Type	Residence Time	Flushing Potential	Tidal Prism	Freshwater Input	Sediment Trapping Efficiency	Turbidity	Susceptibility to Altered Ecological Processes
River mouth estuary	Short	High	Small - large depending on flow	High	Low	Low-high depending on flow	More susceptible to altered freshwater inputs (dams, diversions), altered sediment regime
Tidal bay estuary	Short	High	Large	Low	Low	Low - moderate	More susceptible to altered tidal exchange (mouth manipulations), altered freshwater input (dams, diversions), altered sediment regime
Coastal lagoon	Long	Low	Small	Low	High	Low	More susceptible to altered freshwater inputs (e.g., groundwater pumping) and adjacent land use (e.g., pollution/ nutrient inputs)
Classic estuary	Moderate, depending on size, flow, and tidal range	Moderate	Moderate-large	Moderate	Moderate	Moderate	More susceptible to altered tidal exchange (mouth manipulations), altered freshwater input (dams, diversions), altered sediment regime

Table 3-2: Inherent properties of estuarine types that affect their susceptibility to threats

4. THE HUMAN FOOTPRINT

Human beings are an undeniably prominent feature of the landscape and seascape of West Coast estuaries. While many human activities result in loss of habitat and biodiversity and degradation of ecosystem health, it is important to acknowledge that humans are an integral part of the estuarine ecosystem. Conservation practioners work proactively with human communities to develop management approaches that balance human needs with ecosystem protection. An understanding of patterns of land tenure (ownership), land cover, and predominant land uses in estuary catchments is essential for strategy development as they represent different threats, and different opportunities and pathways for conservation.

Land Cover and Human Uses

Distinct geographic patterns in land cover provide proxies for some major human uses in estuary catchments (**Figure 4-1**). A majority of estuaries in the region (73%) have more than 70% of their adjacent catchment in natural land cover (including forestry lands), almost all of which are located in northern California, Oregon, and Washington. The major land and water uses in the region include forestry, urban, agriculture, port and harbor development, and aquaculture. Urban areas and agriculture, collectively, make up only 19% of land use in estuary catchments in the region (**Figure 4-2a-c**). The remaining 81% is classified as natural landcover.

Forestry: Forestry activities can impact downstream estuaries in a variety of ways. Timber harvest is associated with excessive sedimentation or increases in temperature (Dowd et al. 2008; Crain et al. 2009), which may affect the quality of spawning and rearing habitats for salmonids and other species. Timber operations may also result in the removal of woody debris that is essential to the formation of deep, cold pools that provide escape cover for juvenile salmonids. Forest management in the region has transitioned over the past several decades from focusing on value-liquidation and high-yield production to placing a greater emphasis on sustainability and provisioning of a wide array of non-commercial values, including the restoration or maintenance of biodiversity (Kohm and Franklin 1997). However, incompatible forestry continues to have adverse impacts on estuaries and their catchments, particularly where intensive forest management (e.g., short-rotation clear-cutting) is a predominant practice in the surrounding watershed.

Significant changes in the spatial distribution of forest clear-cutting have taken place between 1996 and 2001 in estuary catchments in the region (**See Figure 4-3**). Although there is still some clear-cutting occurring in northern California coastal watersheds, the vast majority of clear-cut forestry is occurring in coastal watersheds in Oregon and Washington. Indeed, there has been an increase in the amount of clear-cutting between 2001 and 2006.

States regulate timber harvest and post-harvest restoration activities on private and state lands through forest practice rules. While sediment reduction measures have improved substantially in recent years, current regulations leave room for improvement and consistent implementation, monitoring, and enforcement of regulations is a challenge for resource-limited regulatory agencies (Ligon et al. 1999; Rashin et al. 2006). Numerous waterways within estuary catchments are listed as impaired for excessive sediment, turbidity, or temperature with the impairments attributed to forestry practices (Ligon et al. 1999; Rashin et al. 2006) (**Figure 2-5b**). Even with improved forestry practices there is a legacy of past impacts including forest roads,

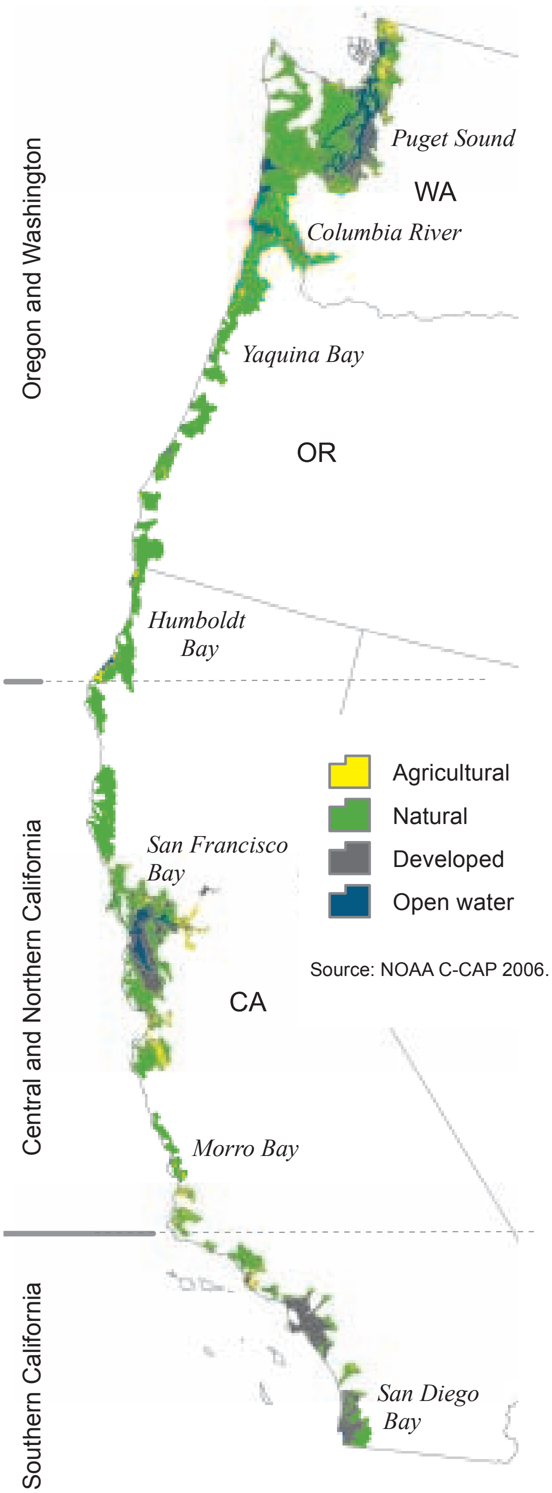


Figure 4-1: Generalized land cover in estuaries and their catchments

altered riparian habitats, and loss of woody debris that will affect aquatic systems, salmonids, and downstream estuaries for years to come.

Agriculture: Over 900,000 acres of West Coast estuary catchment lands are in agricultural use with over 500,000 acres as cultivated land and over 400,000 acres as pasture crops. Some of the most significant concentrations of agricultural lands occur in central and southern California and northern Puget Sound estuaries (**Fig. 4-2a**). Conventional agricultural practices can potentially impact water quality, causing erosion and sedimentation, offsite transport of chemical fertilizers and pesticides, and microbial contamination of estuaries (Dowd et al. 2008). In addition, agriculture can result in habitat alteration, as habitat areas, including wetlands, are converted for cultivation (Ramankutty and Foley 1999). The protection of agricultural lands from flooding often results in building of levees and other hydrological modifications that impact estuarine function and ecological processes.

Agriculture is explicitly exempt from discharge permit requirements under federal clean water laws; however, some states may subject farmers to state clean water laws. In the case of California, farmers are not specifically exempt from permit requirements under the Porter-Cologne Water Quality Control Act, but permit requirements for farmers are typically categorically waived by the Regional Water Quality Control Boards. The Central Coast Water Quality Control Board has recently implemented a new program to regulate agricultural runoff through voluntary implementation of Best Management Practices; the success of this program has yet to be determined (Dowd et al. 2008).

Urban: A large percentage of the West Coast population is concentrated along the coast, and several large urban centers are built around estuaries in the region (Seattle, San Francisco Bay area, Los Angeles). While development on the West Coast is highly concentrated in a few places, the impacts of more sparse development can be seen throughout the region (**Figure 4-2c**). Not surprisingly, southern California's estuaries are the most "altered," their shapes and borders having been most heavily impacted by urban and port/harbor development and reshaping of the shoreline with armoring and revetments.

Development poses a number of potential threats to estuaries. Specifically, urban runoff contains pollutants like pathogens, metals, nutrients, and sediment, which impair estuarine water quality. Urban runoff is regulated through the federal Clean Water Act's laws pertaining to municipal separate storm sewer systems, which require some municipalities to acquire a discharge permit for the various pollutants that enter waterways as runoff. Development also causes habitat conversion, as wetlands and floodplains become hemmed in by roads, houses, and other structures. Further,

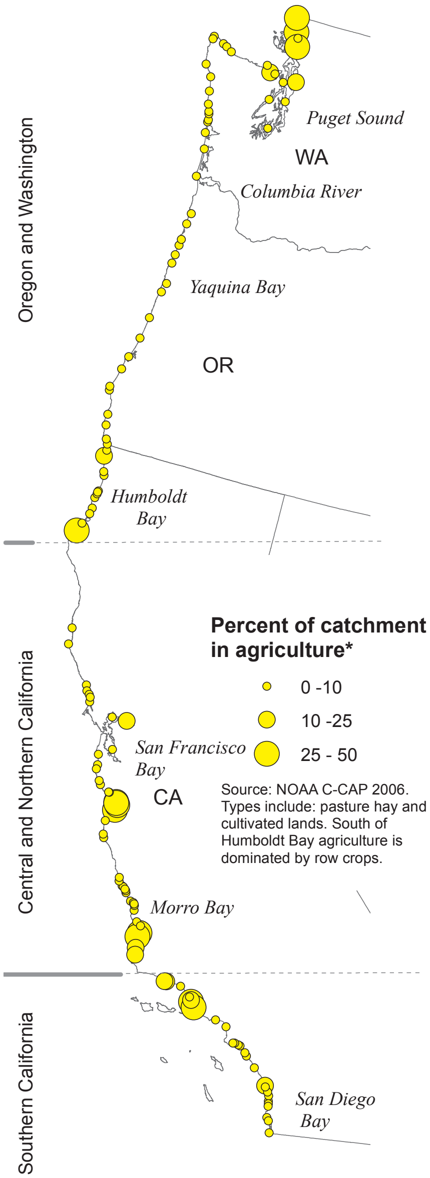


Figure 4-2: Percentage of estuary catchment dominated by different land cover types – (a) agriculture

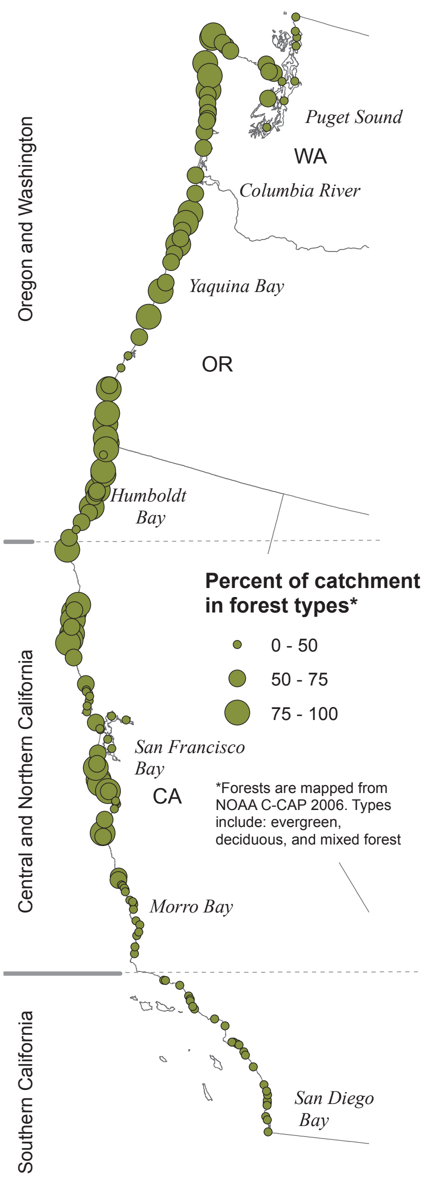


Figure 4-2 (b): forests

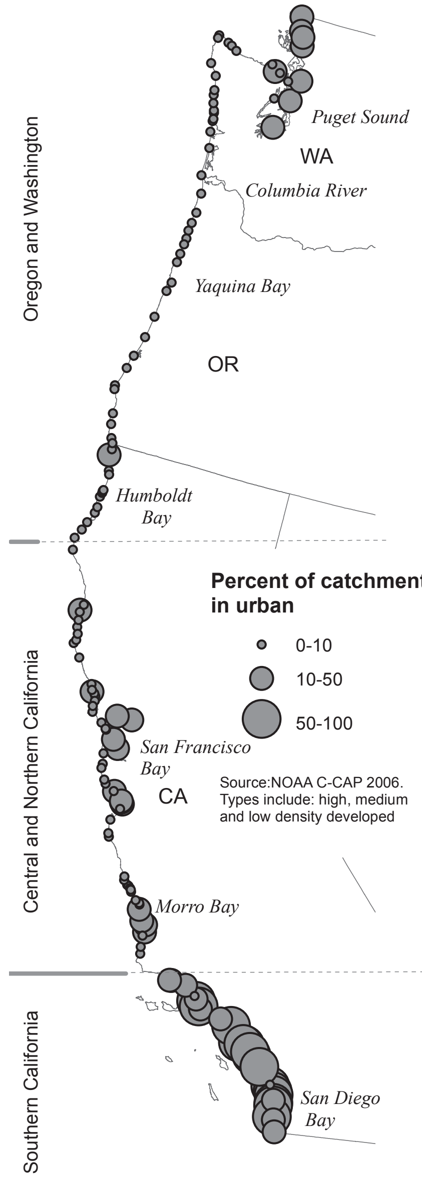


Figure 4-2 (c) urban and developed

hydrological and sediment regimes can become altered as communities seek to protect themselves from flooding of nearby waterways.

Urban development is generally guided by local governments through their comprehensive planning and zoning authorities. States may have some limited oversight of local development, such as California's efforts to oversee local coastal development plans through the California Coastal Act. In Oregon, Goal 16 of the Statewide Planning Goals and Guidelines is specifically aimed at protecting the values of estuaries and associated wetlands. Major hydrological modification projects are often accomplished through the U.S. Army Corps of Engineers, which partners with state and local governments in cost-share agreements on such projects.

Port and Harbor Development: Many of the deep water estuaries—and even some of the shallow water estuaries—in the region have been used as harbors,

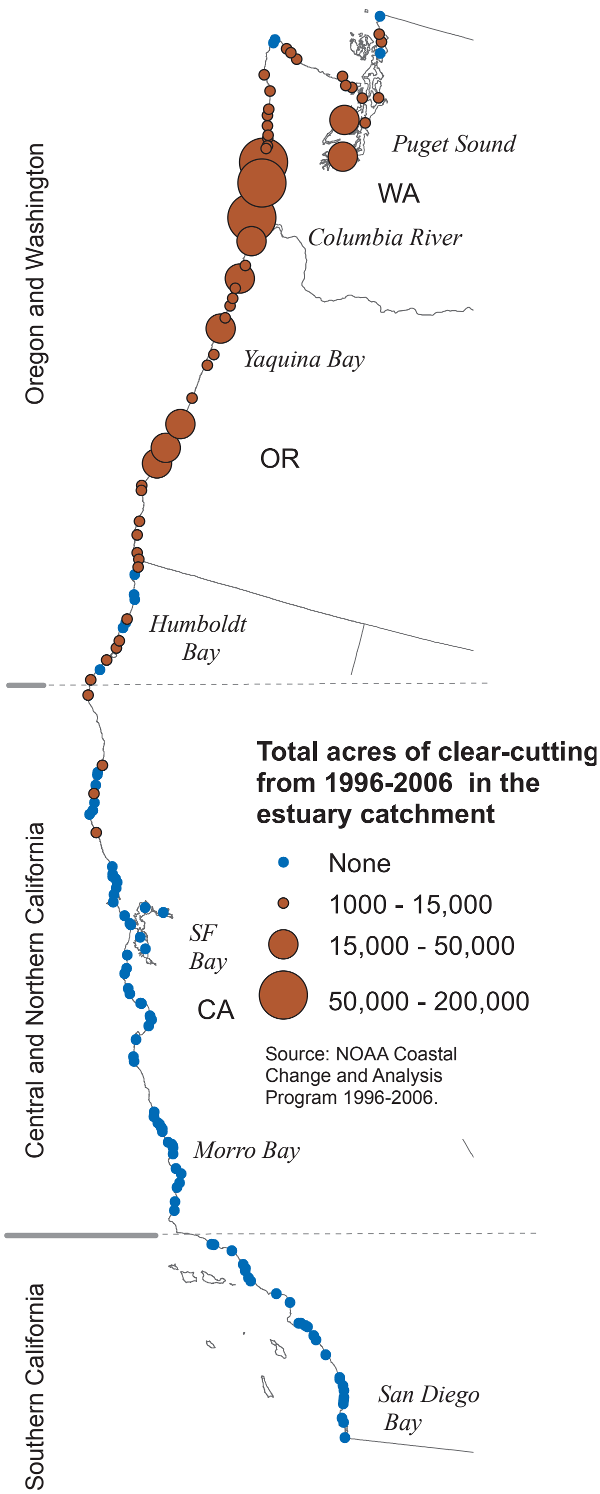


Figure 4-3: Distribution of clear-cut forestry in estuary catchments

some with extensive port and marina development and regular dredging. The major ports on the West Coast, including the ports of Seattle, Long Beach, Los Angeles, San Francisco, and Oakland, are huge economic drivers for the region, generating billions of dollars in revenue annually. Small-boat marinas and fishing ports have resulted in the armoring and alteration of many estuaries throughout the region, including numerous jetties to maintain openings at the mouths of these estuaries (**Figure 2-7**).

Aquaculture Development: Total U.S. aquaculture production (about $1 billion annually) is small as compared to world aquaculture production of about $70 billion. While only about 20% of current U.S. aquaculture production is marine species (NOAA 2010), marine aquaculture production in the U.S. is increasing. There is sustained interest in producing more protein from the sea and aquaculture is viewed as a viable alternative to wild-caught fisheries. Aquaculture investments in West Coast estuaries have largely focused on shellfish production. There are 28 estuaries on the West Coast that have been approved for aquaculture based on their water quality condition, though not all have current aquaculture activities. California grows more than 20 species of fish, shellfish, and aquatic plants but in a limited number of estuaries (CAA 2001; Conte 1990). Regulation in Oregon prevents the development of net-pen salmon aquaculture, so the only active operations produce shellfish. Marine aquaculture in the Pacific Northwest is mostly concentrated in Puget Sound and Willapa Bay.

Conservation Management Status and Ownership Patterns

A relatively small percentage of the land in estuary catchments is in publicly managed protected areas (**Figure 4-4**). Private land dominates the upland

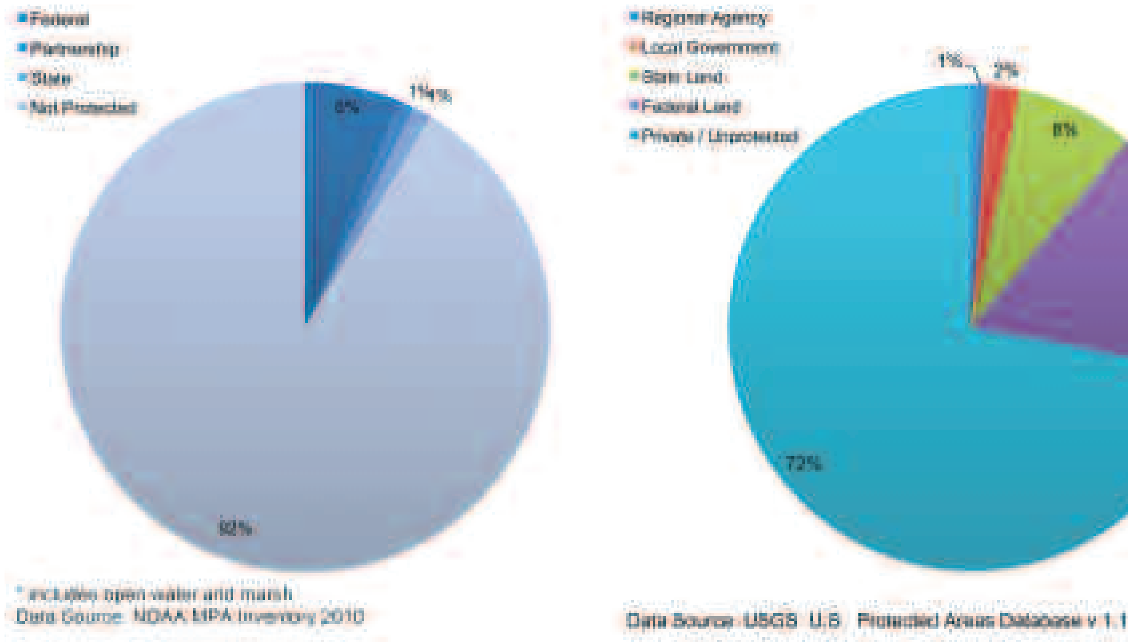


Figure 4-4: Percentage of West Coast estuaries and their catchments in: (a) marine managed areas.

(b) terrestrial managed areas

catchment areas with timber companies owning the largest contiguous tracts of private land. Overall, protected lands account for only 25% of the total area in estuary catchments, however 60% of the estuaries in this study have at least 10% of the land within their catchments under public management (**Figure 4-8**). Some estuaries, especially in central California, Oregon and Washington have a large proportion (50% or more) of their terrestrial catchments in managed areas.

Of the 28% of estuary catchments in publicly managed lands, the top three largest land managers are National Forests (20%), State Trust Lands (e.g., Washington Department of Natural Resources and Oregon Department of Forestry-collectively, 19%), and National Parks (10%) (**Figure 4-6**). National Forests and Parks occur within 88 of the estuary catchments in the region and are concentrated in Washington (Olympic National Park and National Forest) and Oregon (Siuslaw and Rogue River National Forest) with smaller areas in southern California (Los Padres National Forest).

Only 8% of open water and wetland habitats in West Coast estuaries are in marine managed areas (**Figure 4-4**). Only 16 of the estuaries have at least 50% of their open water and associated marsh habitats under some sort of marine managed area designation; these tend to be medium to large lagoons like Drakes Estero and Bolinas Lagoon that are within terrestrial protected areas or national marine sanctuaries.

The representation of estuary types within these managed areas varies across the region and between marine and terrestrial realms (**Figure 4-7**). Most estuary types are fairly well represented (>20% of total area) in terrestrial managed areas, while most estuary types are poorly represented (<20% of total area) in marine managed areas. Only three estuaries have no protected lands or waters.

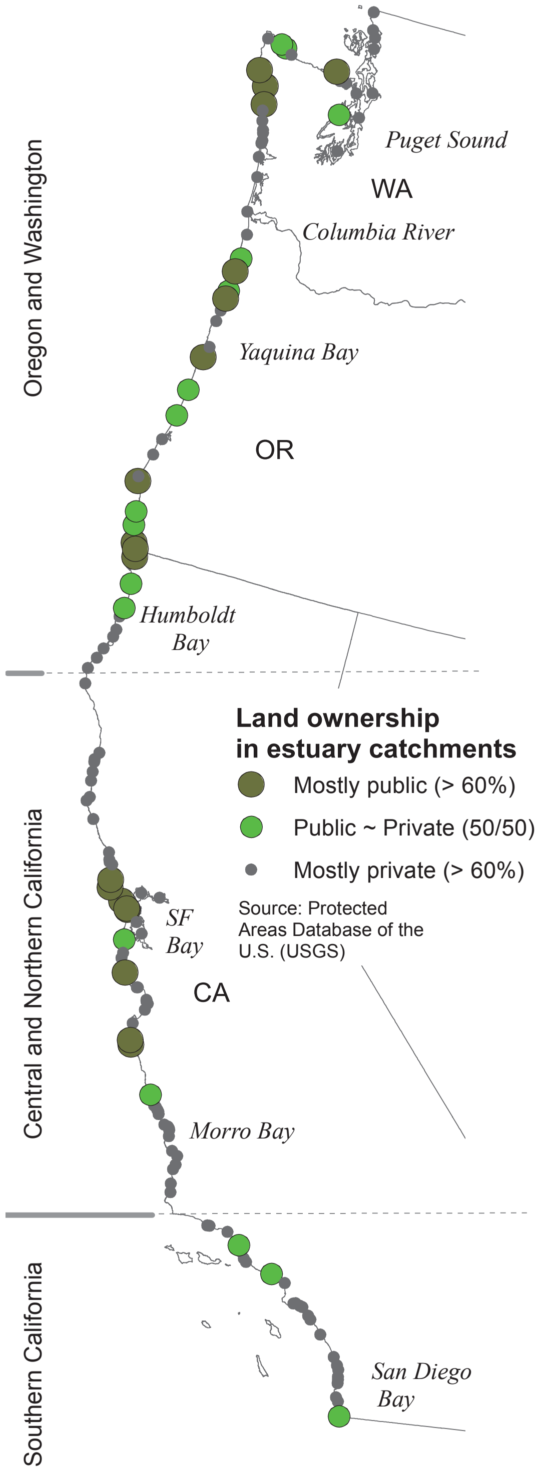


Figure 4-5: Distribution of public and private land ownership in estuary catchments

© Steve Mlodinow

© Kirsten Morse

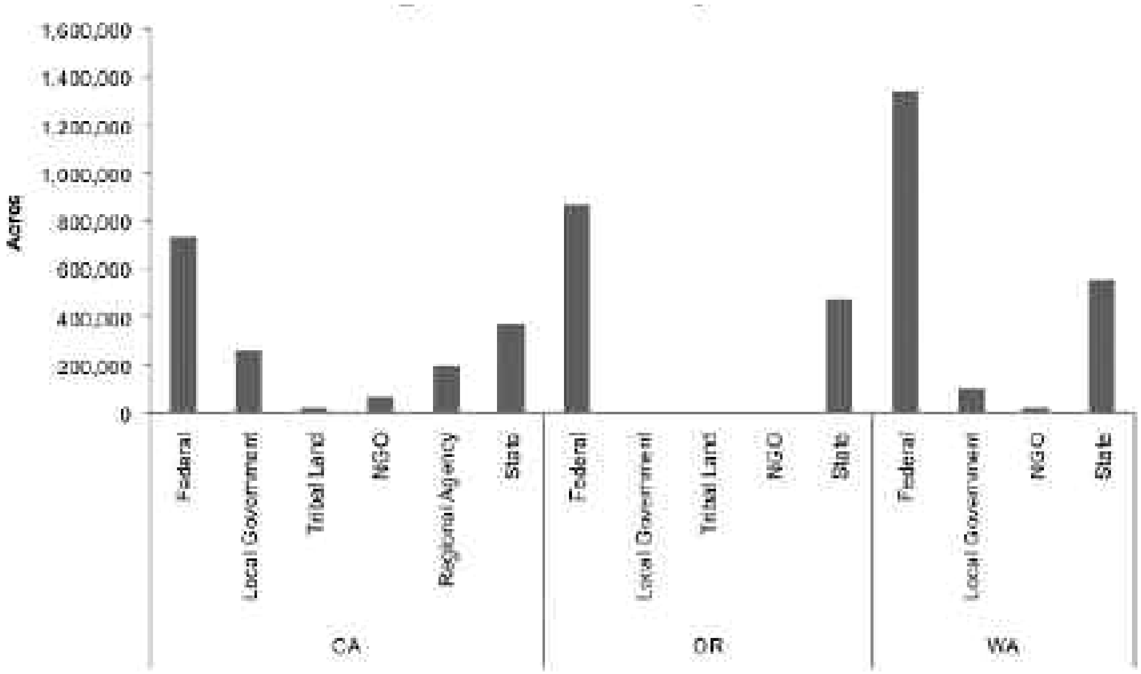


Figure 4-6: Acreage of public lands in estuary catchments by state and federal agencies.

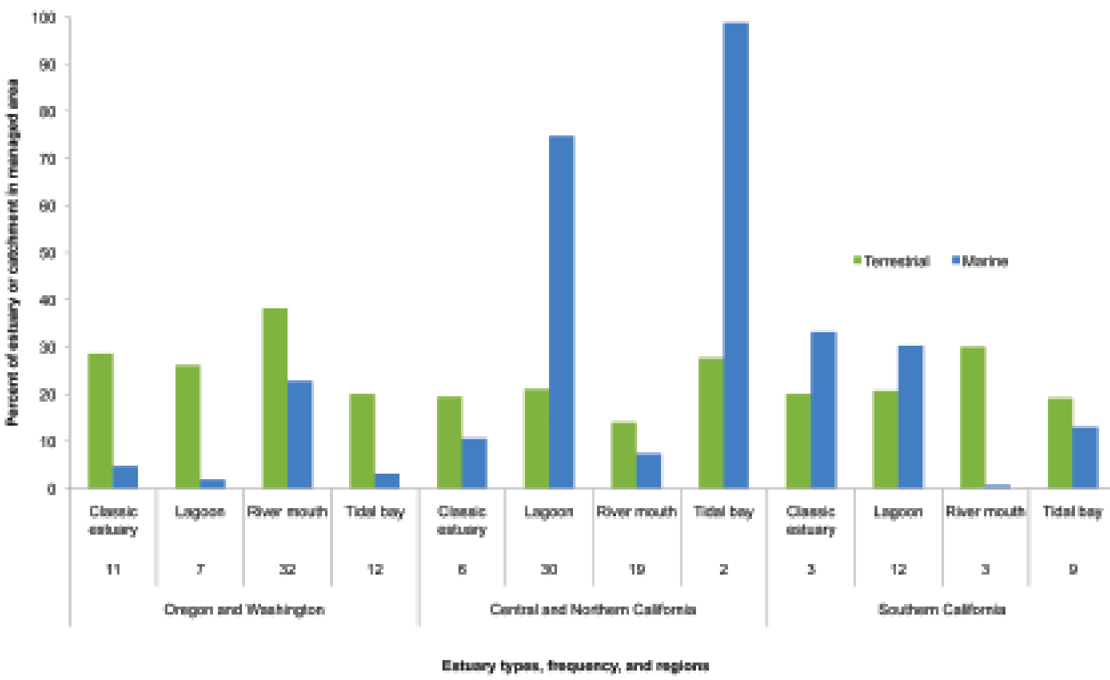


Figure 4-7: Percent of estuary or catchment in managed areas, by region and estuary type.

© Paul Joseph Brown

© Central Coast Wetlands Group

Terrestrial and Marine Management

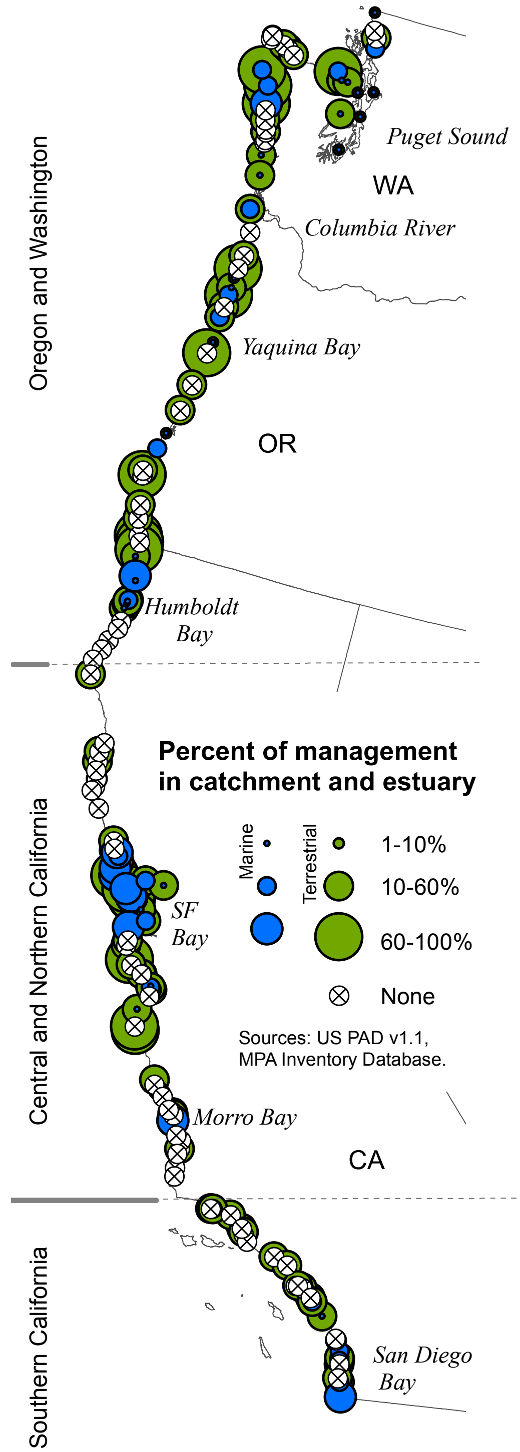


Figure 4-8: Distribution of terrestrial and marine management in estuaries along the West Coast.

TEXT BOX 7: PROGRAMS SUPPORTING ESTUARINE CONSERVATION

A number of federal and state programs and private initiatives have been established to promote conservation in estuaries. A variety of federal programs anchor estuary protection and stewardship efforts, attract public resources and attention, and provide coordination and structure to local conservation efforts. Permanent land and water protection and dedicated funding enables long-term research at these sites, as well as implementation of multi-year, large-scale projects (see for example Wenner and Geist 2001; Gee et al. 2010). Federal programs supporting estuary conservation include:

- EPA's National Estuary Program (NEP) was established by Congress in 1987 to improve the quality of estuaries of national importance. The Clean Water Act Section 320 directs EPA to develop plans for attaining or maintaining water quality in each NEP estuary, of which there are six on the West Coast. In addition, EPA coordinates a multi-agency collaborative to collect data on estuarine condition using nationally consistent monitoring surveys, the results of which are compiled periodically in the National Coastal Condition Reports (EPA 2006).
- Established by the Coastal Zone Management Act of 1972, the National Estuarine Research Reserve (NERR) System is a partnership between NOAA and the coastal states, including a network of 28 areas that are protected for long-term research, water quality monitoring, education, and coastal stewardship. There are five NERRs on the West Coast.
- The National Wildlife Refuge (NWR) program was initiated in 1903, and now has more than 30 sites along the West Coast, 22 of which include estuaries in this assessment. Passage of the National Wildlife Refuge System Improvement Act in 1997 directed the Fish and Wildlife Service to prioritize conservation of fish, wildlife, and plants above all other uses in the NWRs, including activities such as farming and livestock grazing which were once common on refuges.
- The federal government also protects certain high value estuaries through programs created by special Acts of Congress. The Puget Sound Partnership is one of these, established by the Puget Sound Partnership Act in 2008, and coordinates implementation of a Recovery Plan developed through a collaborative, community-based partnership (see http://www.psp.wa.gov/).

State governments also play an integral role in coastal and estuarine protection and stewardship. State natural resource protection laws build on and sometimes surpass federal laws in providing binding protection for natural resources. State agencies provide regulatory enforcement, own and manage land and water, employ experts in a range of disciplines, and fund extensive protection, stewardship, and restoration projects.

Regional efforts offer the possibility of advancing estuary conservation. Initiated in 2006, the West Coast Governors' Agreement on Ocean Health seeks to advance goals related to water quality, habitat protection, development impacts, research, and outreach. The Agreement also underscores the importance of managing activities that affect our oceans on an ecosystem basis (ecosystem-based management, or EBA). Formed in 2008, the West Coast Ecosystem-based Management (EBM) Network is a partnership of six community-based initiatives focused on the sharing techniques and lessons for the successful implementation of EBM along the coasts of Washington, Oregon, and California.

5. PATHWAYS FOR ENHANCED CONSERVATION OF WEST COAST ESTUARIES

© Bridget Besaw

For the purpose of this assessment, terrestrial and marine managed areas include all managed areas (i.e., gap status 1-3; Jennings 2000; Gleason et al. 2006) regardless of the level of protection afforded. Many of these managed areas represent opportunities for working with public agencies or initiatives (**see Text Box 7**) to improve stewardship and protection.

The NWRS, although not exclusively focused on estuaries, plays an important role in coastal protection. National Wildlife Refuges are present at 22 estuaries on the West Coast and include representation of all types of estuaries. Further, the NWRS represents 6% of the total area of open water and marshes in West Coast estuaries. Other agencies that manage significant amounts of land in the region include the National Park Service, Washington Department of Ecology, and the California Department of Fish and Game. These three agencies collectively manage roughly 30% of the open waters and wetlands on the West Coast, and may represent key public partners to engage in estuarine wetland management.

The many federal, state, local, and non-governmental organizations that are engaged in conservation and restoration of West Coast estuaries have made tremendous gains in the last few decades. However, much of this conservation work is very focused on individual estuaries and watersheds and not well-connected across the region. These site-scale actions could be made more effective through coordinated, multi-site conservation grounded in an understanding of the regional context (Merrifield et al. 2011). Doing so requires an understanding of the shared features around which conservation strategies are designed, and the regional strategic pathways through which multi-site conservation can occur.

Multi-Site Strategy Identification in a Regional Context

Regional conservation—and even site-scale action—can be improved by an understanding of regional patterns of biodiversity and threats—as well as an understanding of the opportunities provided by ownership, existing protected areas and human uses. Within this regional context, practitioners can evaluate each individual estuary on the basis of its contribution to regional biodiversity, integrity, conservation potential, and feasibility of action (for an example from northern California, see **Text Box 8**). This approach can facilitate identification of conservation priorities and put conservation actions and investments into a larger setting.

In addition, estuaries that share common threats or other traits may represent opportunities for export of successful single-site strategies or development of multi-site strategies benefitting a group of estuaries. Some important factors that can be used to group estuaries to support identification of these strategies include:

- **Key conservation values:** Identifying and grouping estuaries that share key biodiversity features that different conservation approaches are designed to protect can maximize the effectiveness of conservation actions by focusing on estuaries with the highest conservation value.
- **Key threats:** Threats to biodiversity are at the heart of any conservation problem; a threats-based query can be helpful in grouping estuaries that share common threat factors to guide strategy development across scales.
- **Estuary type:** The classification system presented here reflects the dominant physical dynamics of the estuaries in the region; these are significant to strategy development because they govern not only the

TEXT BOX 8: USING THE REGIONAL CHARACTERIZATION TO INFORM STRATEGIC PRIORITIES—A CASE STUDY

Figure1: Estuaries of California's North Coast Ecoregion (outlined in yellow), including estuary types.

A team of conservation practitioners used the regional database to identify strategic priorities and scope potential conservation approaches within California's North Coast Ecoregion (**Figure 1**), a terrestrial ecoregion with 25 estuaries. This focused assessment of a subset of West Coast estuaries identified gaps in estuarine conservation and opportunities for both multi-site and site-scale strategies to improve protection and stewardship of northern California's estuaries. To flesh out detailed on-the-ground strategies, the practitioners then followed the regional-scale assessment with development of a site-scale conservation area plan for a priority estuary using the approach described in Chapter 2.

The 25 estuaries of California's North Coast ecoregion represent some of the most extensive and valuable coastal wetland habitats in California (>26,000 acres of total estuary area). The supporting watersheds, composed of temperate forests, oak woodlands, and grasslands are used to produce timber, cultivate wine grapes, support tourism, and raise cattle. Most North Coast estuaries are river mouth estuaries (64%) where freshwater inputs are important, though an ecologically diverse system of lagoons also exists. According to the regional analysis, North Coast estuaries and associated catchments are characterized by the following:

- A low level of catchment protection[3] (16%) for the ecoregion as a whole with a greater average level of protection north of Humboldt Bay (20%) and less protection south of Humboldt Bay (10%)
- An exceptionally high degree of natural land cover at the catchment level with only one estuary falling below 50% (Eel River estuary) and nearly all estuaries having >85% natural cover
- Forest-dominated land cover (average = 72%) and minimal agricultural land cover (average = 3%) with consolidated timber production as the prevailing upstream land use
- Ample "room to move" in the face of sea level rise, with wetland migration areas for the period 2000-2100 on average equaling the size of current estuary area
- The region's eight coastal lagoon systems are irreplaceable natural areas of statewide significance, yet the level of protection conferred to lagoon catchments is highly variable (0 – 48%) and insufficient to meet ecological goals (average level of protection <20%).
- Different concentrations and extents of wetland and floodplain habitats that are largely geologically controlled and influenced by past and contemporary land use practices

The review of regional data and rankings has revealed the following set of potential opportunities for ecoregional conservation engagement in estuaries in the North Coast:

- Increase amount of protection in estuaries, especially south of Humboldt Bay
- Increase the amount of catchment area conserved around North Coast lagoons
- Protect and restore key ecological systems and processes by working collaboratively with private owners of large, working landscapes (rangelands, forests, and farmlands)
- Augment public conservation investments dedicated to the protection of climate-resilient estuaries by using the sea level rise analyses to influence regional conservation priorities
- Conduct systematic evaluation of how contemporary sediment and freshwater dynamics impact estuary conditions; refine priorities and threat abatement strategies accordingly
- Conduct a socioeconomic and situational analysis to predict how and where prevailing and likely future management practices (e.g., vineyard expansion, forestry intensification) will improve, maintain, or degrade estuaries and associated habitats

[2] One of California's terrestrial ecoregions extending from the Russian River northward to the Oregon border (coastal Del Norte County) and from the Pacific Ocean eastward to the Inner Coast Ranges (TNC 2001)

[3] Gap 1, 2 & 3; see chapter 4 for conservation management status definitions

- vulnerability to specific threats, but also the likelihood of success of various strategies.
- **Land tenure and conservation management status:** Conservation strategies that are feasible on public lands are often not appropriate for private lands, and vice-versa; it is critical to approach conservation planning with this in mind, and to devise strategies that are appropriate for the ownership context.

As a test, this approach to grouping estuaries was applied to three conservation problems: 1) identifying estuaries that are important for salmonid conservation on public lands, 2) identifying estuaries with the most value for wetland migration during sea level rise in California; and 3) bird conservation on unconverted (natural) private lands.

Salmon conservation: This illustration focuses on identification of river mouth estuaries that are salmon strongholds and dominated by public land-ownership. For salmonid conservation, a focus on river mouth estuaries is appropriate given the special susceptibility of those estuaries to alteration of hydrologic and sediment regimes and the adverse impacts of those changes to salmonid populations that rely on rivers for spawning. This illustration focused on the most viable coho salmon populations, as represented by the salmon stronghold designation, but useful strategies based on a similar sorting of estuaries could also be devised for more degraded populations. Two alternative strategic pathways may arise based on dominant land ownership in the catchments, with public ownership facilitating restoration and direct stewardship strategies, and private ownership more suitable for protection (i.e., purchase or the application of conservation easements) and management or regulatory strategies. A suite of river-mouth estuaries in Oregon and Washington is identified as appropriate for restoration strategies focused on sediment and temperature impaired water bodies, with public agency partners (coho salmon strongholds overlap with predominantly public lands) (see **Figure 5-1**).

Wetland migration during sea level rise: A similar approach can be applied to the identification of potential strategies for promoting adaptation to sea level rise in California estuaries (**Text Box 6**). In this example, the estuaries with the highest acreage in the wetland migration area (>500 acres) were further categorized by their dominant land cover type and the proportion of public and private ownership (**Table 5-1**). Appropriate strategies can then be tailored to the specific land use and ownership context (described in more detail in the following section).

Bird conservation on private lands: Finally, given the dominance of unconverted (natural) private lands in many of the estuary catchments, the database was used to identify estuaries with the highest potential for bird conservation with private partners. Estuaries with greater than 75% private land in their catchments were identified; a subset of those had greater than 75% of their catchments in natural land cover; and some of those estuaries were also associated with Important Bird Areas (**Figure 5-2**). This grouping of estuaries includes many coastwide, but concentrated in northern California, Oregon and Washington.

Strategic Pathways

By focusing on specific biodiversity elements, land cover, and threats at multiple sites, conservation practitioners can group estuaries that have the potential to benefit from shared strategies. Several main strategic pathways, and the opportunities embedded therein, are: conservation through government protection or stewardship, conservation on working landscapes and seascapes, restoration of degraded habitats and ecological processes in both a public and private context, and adaptation to climate change. All four of these pathways are already being followed to some extent across the West Coast, but significant opportunities exist to build on these foundations and to link efforts across the region.

Public Land Protection and Stewardship

While this analysis reveals that private land dominates the upland catchment areas, publicly protected lands account for 28% of the area in estuary catchments, and 60% of estuaries have at least some sort of protected lands within their catchments. Publicly-owned lands represent one of the greatest opportunities for creative and flexible approaches to conservation. While significant gains in land and water protection in estuaries have been made over the last few decades, public agencies have an important role to play in advancing those trends. Several federal and state programs have historically provided and continue to supply funds for land protection, including (but not limited to) the ones discussed below.

- The Land and Water Conservation Fund (LWCF) provides money and matching grants to federal, state, and local governments for the acquisition of land and water, and easements on land and water, for the benefit of all. LWCF has helped state agencies and municipalities acquire nearly seven million acres of land and easements.
- The Coastal and Estuarine Land Conservation Program (CELCP) provides state and local governments with matching funds to purchase significant coastal and estuarine lands, or conservation easements on such lands, from willing sellers. The program has protected more than 45,000 acres of land through projects funded between 2002 and 2008.
- The North American Wetlands Conservation Act (NAWCA) of 1989 provides matching grants and matching funds to partnerships to carry out wetlands conservation projects in the United States, Canada, and Mexico for the benefit of wetlands-associated migratory birds and other wildlife. From September 1990 through March 2011, some 4,500 partners in 2,067 projects have

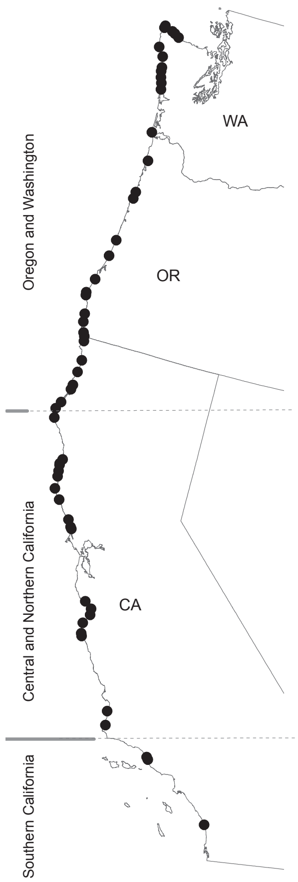


Figure 5-1(a): River mouth estuaries

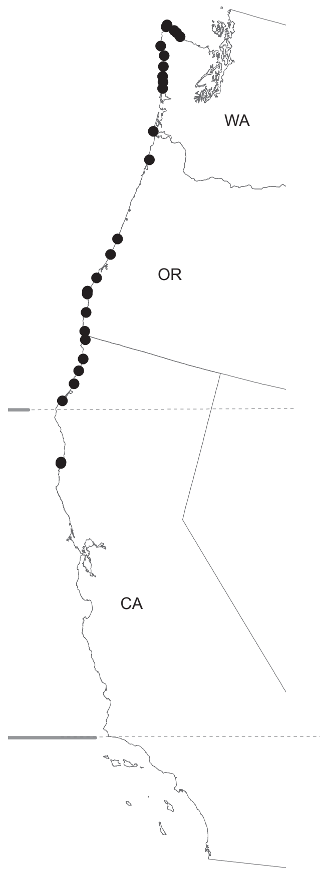


Figure 5-1(b): River mouth estuaries that are coho salmon strongholds

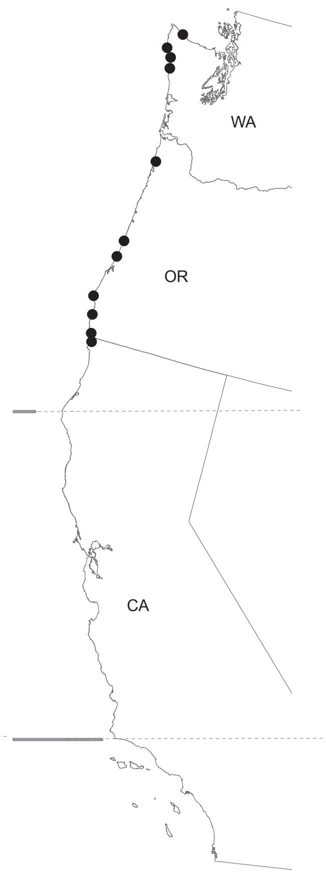


Figure 5-1(c): River mouth estuaries that are coho salmon strongholds and in mostly publicly-owned catchments

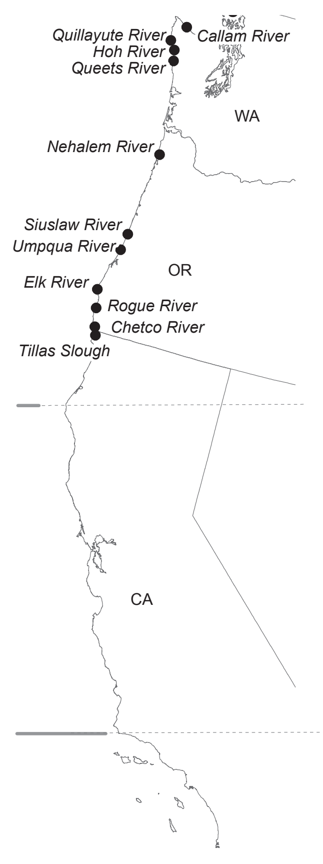


Figure 5-1(d) River mouth estuaries that are coho salmon strongholds, in mostly publicly-owned catchments, and are impaired by sediment or temperature.

received more than $1.1 billion in grants. They have contributed another $2.32 billion in matching funds to affect 26.5 million acres of habitat and $1.21 billion in non-matching funds to affect 234,820 acres of habitat.

- In California, the State Coastal Conservancy provides funding, expertise, and guidance to protect, restore, and enhance coastal resources. In 2008 the Coastal Conservancy provided more than $102 million in grant funding.
- The Oregon Watershed Enhancement Board (OWEB) operates a grant program that helps restore and protect rivers and wetlands. OWEB has provided funds for thousands of projects to protect clean water and restore fish and wildlife habitat across the state.
- State land acquisition in Washington is administered by three agencies: Parks and Recreation Commission, the Department of Fish and Wildlife (WDFW), and the Department of Natural Resources Natural Areas Preserves program.

The obligation of public agencies in estuary conservation is not limited to land acquisition, but extends to stewardship as well. Often the human activities permitted on public lands cause extensive habitat degradation. For example, clearcut forestry was historically permitted on public lands—and is still permitted in many places—but results in extensive erosion, degraded waterways, and substantially altered riparian habitat. Agencies that manage public lands need to take coordinated steps to abate threats associated with unsustainable uses of public land, and conduct restoration of lands that have been degraded by harmful practices. Land management agencies should establish protection of biodiversity and ecosystem services as the priority goals of land management for estuary waters and catchments, and coordinate the development of comprehensive management plans according to that objective. Other uses of land should be permitted if proponents can demonstrate that they are not inconsistent with this objective, and harmful or unsustainable practices should be phased out.

Estuary Name	Wetland Migration Area (acres)	Percent Agriculture	Percent Urban	Percent Natural	Natural % Protected	Natural % Private
San Francisco Bay - South Bay	22,293	5.4	58.4	36.2	57.3	42.7
San Francisco Bay - Suisun Bay / Carquinez Straight	17,464	4.8	9.0	86.3	31.7	68.3
San Francisco Bay - San Pablo Bay	13,534	4.9	21.7	73.4	50.0	50.0
San Francisco Bay - Central Bay	6,241	7.0	79.7	13.4	53.9	46.1
Humboldt Bay	5,892	64.5	12.4	23.1	30.4	69.6
Eel River Estuary	4,243	67.9	0.7	31.4	22.4	77.6
Mugu Lagoon	3,734	33.3	20.1	46.6	72.7	27.3
Elkhorn Slough	3,142	38.9	6.8	54.3	59.8	40.2
Santa Ana River	1,516	6.7	80.9	12.4	60.6	39.5
Watsonville Slough	1,160	57.5	4.7	37.8	62.6	37.4
San Diego Bay	947	5.9	46.8	47.3	69.6	30.5
Salinas River	835	42.8	6.0	51.2	49.3	50.7
Tijuana Estuary	615	8.7	7.7	83.6	99.4	0.6
Tillas Slough	555	39.5	1.3	59.3	10.6	89.4

Table 5-1: Land cover in potential wetland migration area in California estuaries (estuaries with >500 acres in migration area) assuming 1.4m sea level rise.

Conservation on Working Landscapes and Seascapes

The significant acreage of privately-held land in West Coast estuary catchments, combined with the land-based source of many of the most significant threats, indicates a need for more innovative conservation in working landscapes (Figure 4-6). The most significant private land uses in the study region—urban development, timber harvest, and agriculture production—are associated with well-characterized threats like habitat conversion, runoff and sedimentation. These areas represent opportunities for demonstrating the effectiveness of restoration partnerships with landowners (Kilgore and Blinn 2004; Schaaf and Broussard 2006; Suzuki and Olson 2007). Text Box 9 describes such a partnership between farmers and conservationists, in which farmers in floodplains are paid to flood their fields for wildlife habitat during their regular crop rotations.

15% of estuaries have both very low levels of protection (< 20%) and a very high proportion of natural land cover in the catchment (>70%); these estuaries may represent some of the best opportunities for private land conservation. Topping this list are California estuaries, particularly those north of the San Francisco Bay Area, including the Gualala River, Alder Creek, and Tenmile River. Conservation easements are an important tool for maintaining such areas in a largely natural state, but may also be applied to curtail specific detrimental practices, while allowing other less harmful land uses. Conservation easements, or conservation restrictions, are legally binding agreements between landowners and land trusts or government agencies that place limitations on private properties to protect the natural resources associated with the parcel. An easement is either donated or sold by the private landowner and restricts some uses of the land or prevents development from taking place. Conservation easements protect land for future generations, yet they also allow owners to maintain many private property rights, live on and use their land, and gain income and tax benefits. An easement targets only the property rights essential to the protection of specific conservation values, and each is individually tailored to meet the landowner's needs. TNC and other conservation groups have pursued conservation easements for private lands for ecological, agricultural, and aesthetic reasons.

[4] (http://www.mcatoolkit.org/Field_Projects/Field_Projects_US_Washington_2_Port_Susan_Bay.html)
[5] (http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHCP/Pages/aqr_aquatics_hcp.aspx)

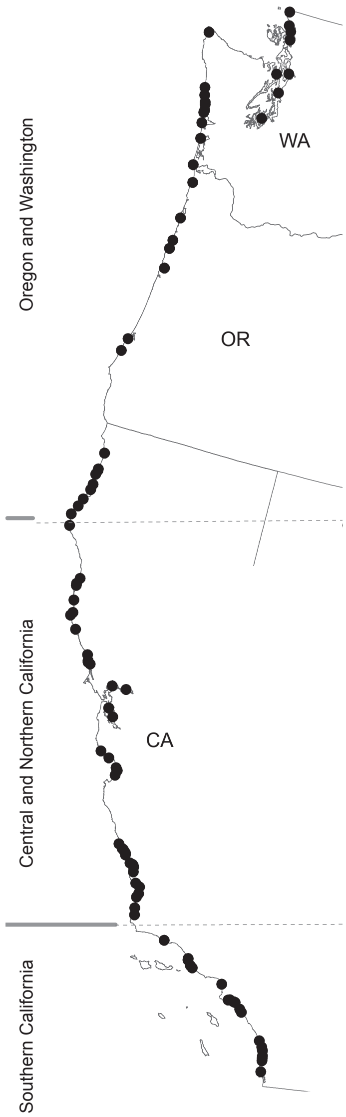


Figure 5-2 (a): Estuaries with high natural land cover

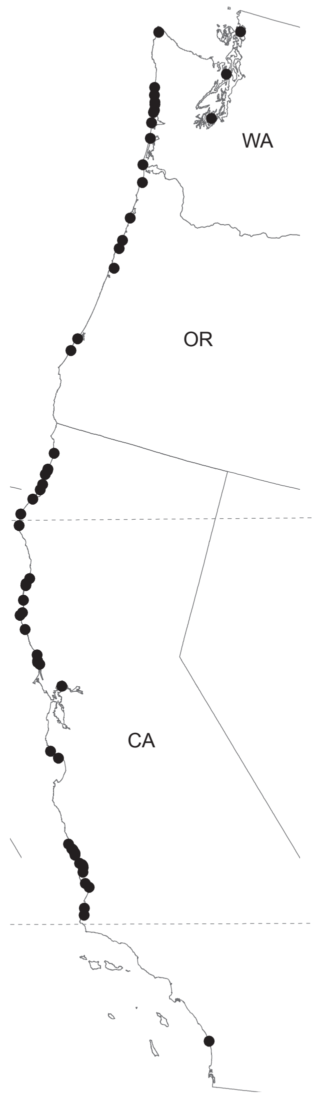


Figure 5-2(b): Estuaries with high natural land cover that are in catchments dominated by private land ownership

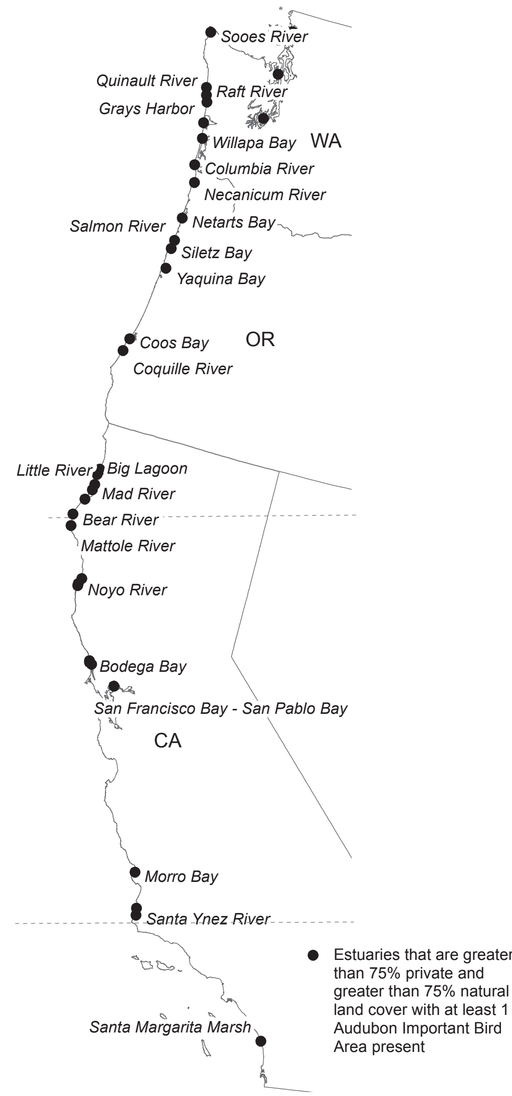


Figure 5-2(c): Estuaries with high natural land cover in catchments dominated by private land ownership with at least one Important Bird Area

While most of the open water environment is part of the public trust, private interests in subtidal lands can be acquired through leasing and purchase. These lands are usually leased and purchased by commercial entities for various purposes (such as private docks and piers, harvest of natural resources, and aquaculture), and these uses suggest potential conservation partnerships. Specifically, the aquaculture industry would benefit from conservation actions that improve ambient water, and may be a natural partner in such conservation initiatives. Conservation leasing and purchase of sub-tidal lands may also be used as a tool for conservation (Beck et al. 2004); submerged lands available for lease include a diverse array of ecosystems such as marshes, seagrass meadows, oyster reefs, tidal flats, clam beds, and scallop beds (Beck et al. 2004).

TNC has pioneered conservation of sub-tidal lands through purchases in California and Washington. A large acquisition was made in Port Susan Bay, Washington in 2001; TNC purchased over 4,000 acres at the mouth of the Stillaguamish River in order to preserve and restore functional estuarine habitats[4]. This project has helped with the development of an aquatic Habitat Conservation Plan (HCP) in the state. Washington's Department of Natural Resources is developing the aquatic HCP to protect sensitive, threatened, and endangered species while ensuring that business uses of aquatic areas can continue[5].

Ecological Restoration

Incompatible human uses of estuaries and their catchments have resulted in substantial degradation of natural habitats and ecological functions. For example,

TEXT BOX 9: IMPROVING STEWARDSHIP ON PRIVATE AGRICULTURAL LANDS IN PUGET SOUND

On the Stillaguamish, Skagit, and Samish River Deltas in north Puget Sound, much of the historic estuary has been diked and converted to farmland. The loss of this habitat has had large impacts on estuary-dependent fish and shorebirds. The delta region is not only a site of regional importance for shorebirds, it is among the ten most important shorebird sites between the Mexican and Canadian borders. More than three dozen shorebird species have been reported, close to a third of which are of significant conservation concern due to declining population and habitat trends.

While substantial habitat restoration is critical to improving system function, full restoration is not possible, or even desirable, in the context of today's land ownership patterns and the food needs of the region's growing population. In an effort to build the habitat values of farmland as well as build productive relationships with the farming community, The Nature Conservancy has initiated a Farming for Wildlife program that pays farmers to flood farm fields for one or two years during their normal crop rotation. This creates ephemeral non-tidal shallow water habitat for migrating and wintering shorebirds, mimicking habitats that may occur on an unconstrained river delta and a natural disturbance regime.

A pilot project on three farms demonstrated that temporary flooding could work successfully to attract birds. Current research is focusing on the economics for the farmer, including reduced costs of inputs due to elevated soil nutrient levels and reduced crop pathogens. A partnership has developed with the Natural Resources Conservation Service which is beginning to provide financial incentives for farmers to adopt the practice.

Puget Sound and San Francisco Bay are estimated to have lost 73% and 95%, respectively, of their salt marshes and wetlands (Restore America's Estuaries n.d.). The current population of Olympia oysters is only a tiny fraction of its historic numbers (Beck et al. 2009). At least 100 estuaries, out of the total 146 estuaries in this study, have at least one waterway listed as impaired on the EPA's 303(d) list. A broad commitment to ecological restoration is essential if estuaries are to continue to provide their functions and services to people and wildlife. Further, if restoration focuses primarily on trying to recreate the structure of a historical habitat, it may not reflect the realities of present-day conditions or future climate change scenarios. In contrast, restoration focused on ecological processes and functions and designed in the context of anticipated sea level rise and other climate change impacts can help to set the stage for the future.

Restoration of ecological processes and functions entails returning the timing, magnitude, and pattern of physical, chemical, and biological processes to values within the natural range of variation (Beechie et al. 2010; Gee et al. 2010). This approach can benefit multiple species and habitats simultaneously, and can also provide societal benefits such as floodwater management, reduced soil erosion, and improved drainage. Restoration of ecological processes may also help ecosystems maintain functionality while adjusting to climate change (Beechie et al. 2010). Types of restoration of ecological processes and functions might include:

- **Restoration of natural tidal exchange:** The removal of dikes, dredge spoil, and other impediments to tidal exchange from areas modified for agriculture or development can help restore tidal processes and natural wetland function.
- **Restoration of natural freshwater flows:** Many human activities have the potential to influence inflow conditions in estuaries, including diking and levees, freshwater diversion, consumption of groundwater, and instream and offstream impoundments. Restoration of more natural flow conditions can benefit estuarine species, including salmonids, and better support natural sediment transport and its habitat-maintenance function.
- **Restoration of nutrient regimes:** Efforts to reduce nutrient inputs from estuary catchments and agricultural and urban runoff can reverse the adverse impacts of altered nutrient regimes on estuarine systems.
- **Restoration of natural sediment processes:** Restoring the natural movement of sediments within an estuarine catchment can benefit both habitat development and resident species and is critical for maintaining marsh elevations in the face of sea level rise.
- **Restoration of habitat diversity:** The level and caliber of ecological function in estuaries depends to some degree on the complexity of habitats and their connectivity. In some estuaries, the greatest ecological return on restoration investment may come from focusing on higher elevation habitat types when this would deliver greater improvements in processes, productivity, diversity, or resilience to climate change impacts.
- **Restoration of nurseries and migration corridors:** Although substantial state and federal funding is directed toward the restoration of commercially and recreationally important species such as salmon, these restoration initiatives rarely, if ever, focus on the critical nursery and migration corridor roles of estuaries in supporting these species.

Restoration of natural processes and functions in estuaries is difficult. The convergence of marine, terrestrial, and freshwater realms in the estuary results in numerous agencies with jurisdiction over different aspects of the same resources, which sometimes hampers restoration (Baird 2005; Crain et al. 2009). In addition, permit processes designed to review projects for their environmental impacts (NEPA and its state analogues) were not created with restoration projects in mind; this can lead to inefficiencies and inconsistencies in the review process.

Nevertheless, recognition of the loss of estuarine habitats and functions has led to substantial public and private investments in restoration. In 2000, Congress passed the Estuary Restoration Act and charged five federal departments with restoring one million acres of estuarine habitat by 2010. The Act's implementing agencies, the Fish and Wildlife Service, Natural Resource Conservation Service, Environmental Protection Agency, Army Corps of Engineers, and NOAA comprise the National Estuary Council that oversees funding expenditures and implementation of the National Estuary Strategy. Although the Act represents a substantial increase in federal investment in estuarine restoration, it has fallen far short of its numeric goals. According to the National Estuaries Restoration Inventory, the database created by NOAA to track progress of this goal, as of 2008 less than 200,000 acres nationwide have been created, rehabilitated, and reestablished, and only 11,532 acres of which are in the Pacific Region (Washington, Idaho, Oregon, and California) (NOAA 2008; **Figure 5-3**).

Private entities and partnerships between private and public entities also make substantial contributions to restoration of estuaries, their watersheds, and the near-shore environment. National NGOs such as TNC, Restore America's Estuaries, Ducks Unlimited, and Audubon bring capacity, knowledge, and financial resources to estuary restoration and protection efforts. TNC alone is working in more than 20 estuaries nationwide. Private businesses are also involved in substantial estuary and watershed restoration, particularly as a mitigation strategy under the Clean Water Act.

In addition, partnerships among government, NGOs, and business interests have formed in estuaries and coastal watersheds to develop plans, coordinate efforts, and build resources for recovery of species and habitats. Examples of public/private partnerships working to protect and enhance aquatic habitats include the TNC/NOAA Community Restoration Partnership (**Text Box 10**), the Corporate Wetlands Restoration Partnership (www.cwrp.org), and the San Francisco Bay Joint Venture (www.sfbayjv.org). The importance of partnerships is reflected in the priority given to them in federal funding programs such as EPA's Targeted Watershed grants, U.S. Fish and Wildlife Service's Partners for Fish and Wildlife, NOAA's Community-based Restoration Program, and Natural Resource Conservation Service's Cooperative Conservation Partnership Initiative. There are many other examples of innovative approaches to ecological restoration (**Text Box 11**).

Coastal Resilience to Climate Change

Climate change is already causing a variety of effects in West Coast estuaries. The human response to climate change will be one of the most critical factors in the persistence or demise of coastal natural resources. For example, if our coastal communities respond to the threat of sea level rise by hardening shorelines—using structures like sea walls and bulkheads—valuable natural systems will be prevented from migrating inland as water levels rise, leaving them to drown in place and erasing the contribution of these natural systems to overall coastal resilience. Structural shore protection disrupts the sediment supply, resulting in erosion to adjacent or down drift areas and hindering the formation and adaptation of many shoreline features. In addition, these structures impair public access as water levels rise.

Some areas of our shoreline are already hardened, and have experienced significant ecological change as a result (**Figure 2-4**). However, in less heavily developed areas, natural shorelines—and the processes that maintain them—still exist and should be protected. Development in coastal areas that are vulnerable to inundation from sea level rise or coastal hazards not only causes direct habitat conversion, as wetlands or floodplains are modified to accommodate structures, but will invariably result in future calls for shoreline protection and modification. Natural systems perform a wide variety of economically valuable functions including water quality protection, commercial and recreational fish production, flood mitigation, recreation, carbon storage and storm buffering. They also provide important habitat for plants and wildlife. Shoreline vistas, beaches and open spaces define coastal community character and quality of life for residents and visitors. They provide all these values at almost no cost. These benefits would be expensive—if not impossible—to replicate with human engineered solutions.

There are three generally-recognized categories of response to sea level rise: protection, accommodation and retreat (CCSP 2009). Protection refers to engineering barriers to inundation, accommodation to elevation and other strategies for minimizing the impact of inundation, and retreat to simply moving structures out of the way. Although engineered protection of critical infrastructure will undoubtedly be necessary in some places, other areas provide opportunities for accommodation and managed retreat that allow human communities and natural resources to coexist on the landscape over time. Specific strategies to promote accommodation and managed retreat vary depending on current land cover and ownership patterns (**Text Box 6**).

Federal and state agencies on the West Coast are involved in numerous efforts to develop information and prepare for climate change impacts to the resources they manage. EPA's Climate Ready Estuaries Program is working through

TEXT BOX 10: IMPROVING STEWARDSHIP ON PRIVATE AGRICULTURAL LANDS IN PUGET SOUND

Since 2001, NOAA's Community-based Restoration Program has partnered with TNC to implement innovative conservation activities across the United States. The partnership places a particular emphasis on restoring shellfish ecosystems and other marine habitats that serve as nurseries for juvenile fish. Projects are selected through a competitive process, and preference is given to those that are within TNC's priority conservation areas and are closely coordinated with local TNC staff. Since 2001, the Partnership has:

- **Leveraged more than $5.7 million from NOAA**
- **Leveraged $7.7 million from state governments, non-federal partners, and NGOs**
- **Funded 95 community-based restoration projects in 20 states.**

In California, Oregon, and Washington, the partnership has funded over 30 projects, including steelhead trout habitat restoration in the Santa Clara River watershed (CA), native oyster restoration in Ventura County (CA), oyster and seagrass restoration in Netarts Bay (OR), and invasive marsh grass eradication in North Puget Sound (WA).

the National Estuary Program (NEP) to develop information and tools to prepare NEP sites and coastal communities for climate adaptation. The Fish and Wildlife Service is currently developing a national fish and wildlife climate adaptation strategy, and establishing research consortiums called Landscape Conservation Cooperatives. These cooperatives are formal science-management partnerships among federal agencies, states, tribes, universities, and other entities that will engage in biological planning, conservation design, and research that will assist land managers with implementation of conservation strategies. NOAA's Office of Ocean and Coastal Resource Management oversees a range of programs providing research, technical assistance, and funding to improve

TEXT BOX 11: ADVANCES IN RESTORATION ON THE WEST COAST

Restoration of ecological processes can benefit multiple species and habitats simultaneously, and can also provide societal benefits such as floodwater management, reduced soil erosion, and improved drainage. Restoration of ecological processes may also help ecosystems maintain functionality while adjusting to climate change (Beechie et al. 2010). A few examples of ecological process restoration on the West Coast include:

- **At Port Susan Bay, in Puget Sound, TNC is preparing to restore natural tidal influence to over 148 acres of marsh habitat at the mouth of the Stillaguamish River by removing a dike. The project will have substantial effects on the whole estuary by increasing the residence time of freshwater in the estuary and restoring some connectivity between the river and existing tidal marshes north of the project site. Under tidal influence, freshwater can spread across a broader area, slowing down and delivering sediment, nutrients, fish, large wood, and other materials to marshes.**
- **At Fisher Slough—a tidally influenced wetland complex, part of the Skagit River estuary in Puget Sound—TNC is successfully partnering with local farmers and dike and drainage districts in the restoration of 60 acres of high-quality tidal marsh habitat and the removal of barriers to fish passage. While the project converts some farmland to habitat, it will also improve farming conditions on adjacent lands, reduce infrastructure maintenance costs, and simplify infrastructure operation.**
- **In the late 1990s and early 2000s, the Elkhorn Slough Foundation, TNC, Natural Resources Conservation Service, and the Resource Conservation District conducted restoration projects in the Azevedo Marsh to reduce sediment and nutrient inputs into Elkhorn Slough. Restoration consisted of installing native vegetation buffer strips near the high tide mark and replacing traditional row crops with low erosion crops requiring less tillage and fertilization. Water quality monitoring before and after restoration demonstrated that these actions resulted in significant decreases in nutrients and turbidity (Gee et al. 2010).**
- **In 2007 and 2008, the National Park Service and partners conducted the first major phases of restoration on 550 acres at the head of Tomales Bay, CA known as the Giacomini Wetlands (National Park Service n.d.). The project focused on removing impediments and conditions that constrain natural process and functions, including removing levees, tidegates, culverts, and agricultural infrastructure; filling in drainage ditches; recreating tidal sloughs and creeks; and shifting creeks into historic alignments. Early signs indicate improvement in water quality and use of the wetlands by migratory birds.**

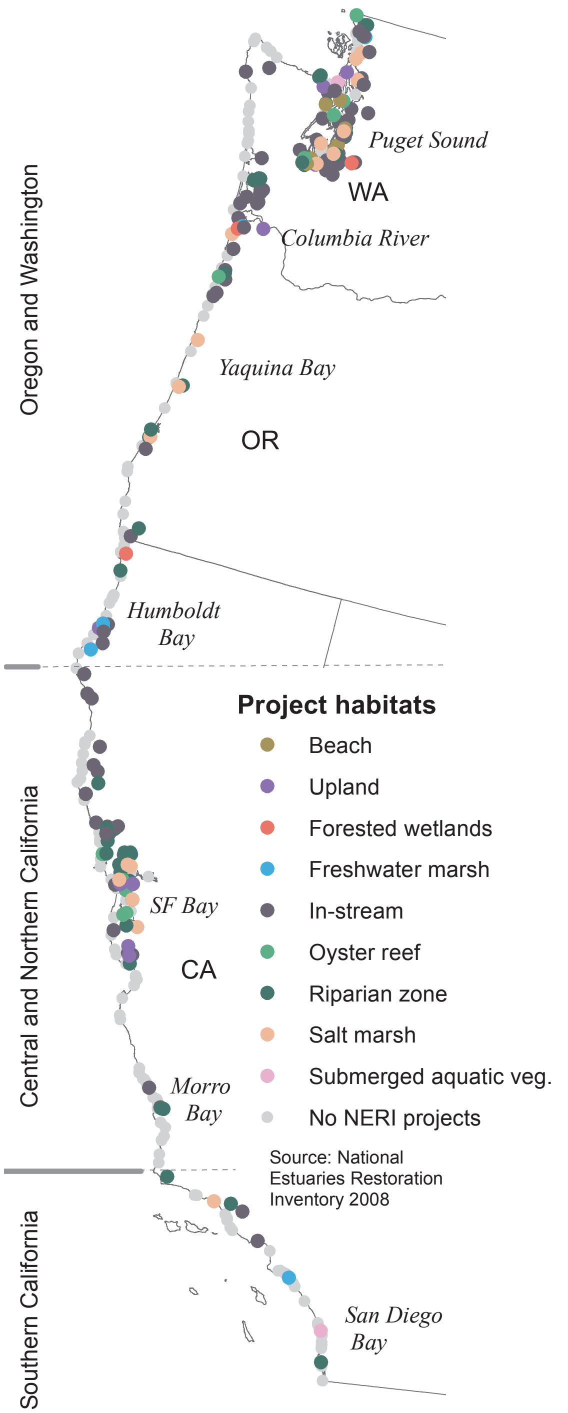


Figure 5-3: Distribution of National Estuarine Restoration Inventory projects

coastal and estuarine conservation. Programs include the Shoreline Management Technical Assistance Toolbox and the Cooperative Institute for Coastal and Estuarine Environmental Technology, which are working to improve access to scientific information for addressing sea level rise and management tools and methods for alternative shoreline stabilization.

In 2009, the California Natural Resources Agency—together with numerous other state agencies—released the California Climate Adaptation Strategy. This document summarizes the best science on climate change impacts in seven specific sectors (public health; biodiversity and habitat; ocean and coastal resources; water management; agriculture; forestry; and transportation and energy infrastructure) and provides recommendations for managing those impacts. Nevertheless, many California agencies and organizations that have had longstanding concerns about sea level rise find they have limited authority to deal with it in the course of their mandated activities. The Ocean Protection Council, California Coastal Commission, San Francisco Bay Conservation and Development Commission (BCDC), and State Coastal Conservancy—among other state agencies— have been evaluating their authority to integrate sea level rise into their work, and have tried to establish formal agency policy on sea level rise planning and response.

In 2009, the Washington State legislature passed legislation requiring an integrated climate response strategy, and the Steering Committee guiding the development of that strategy formed four separate Topic Advisory Groups (TAGs) to develop draft recommendations for different sectors. TAG3 was directed to consider impacts, key vulnerabilities, and draft adaptation strategies for species, habitats, and ecosystems. The resulting strategies focused on increasing habitat connectivity and representation, enhancement of resilience, reducing vulnerability, and incorporating projections into planning.

In October 2009, Oregon's Governor Kulongoski asked the directors of several state agencies, universities, research institutions, and extension services to develop a climate change adaptation plan. The plan was to provide a framework for state agencies to identify authorities, actions, research, and resources needed to increase Oregon's capacity to address the likely effects of a changing climate. The Framework lays out expected climate-related risks, the basic adaptive capacity to deal with those risks, short-term priority actions, and several steps that will evolve into a long-term process to improve Oregon's capacity to adapt to variable and changing climate conditions. It will be necessary to continue to develop adaptation strategies and plans, in particular at the regional and local level.

6. A REGIONAL VISION AND GOALS FOR IMPROVED ESTUARY CONSERVATION

© Steven Mlodinow

In order to address the threats to West Coast estuaries outlined here and reverse the decades-long trend of degradation, government agencies, estuary conservation practitioners, resource managers, and coastal communities should work together to develop a regional vision and agenda that will significantly advance the conservation of West Coast estuaries. In a strategic planning context, the vision identifies the desired future state, goals are the specific outcomes (ecological, social) that are needed to achieve that vision, and strategic pathways identify how to get there. In the interest of beginning a multi-stakeholder dialogue on vision and goals for estuarine conservation, the following is offered as a starting point:

Regional Vision: Key ecological processes, functions, and ecosystem services are maintained or restored in estuaries throughout the West Coast region to protect the full range of ecological and human use values.

Goal 1) Establish a regional estuaries program for the West Coast under the authority of a lead agency, to provide a policy framework, set regional indicators and milestones, administer funding, develop a body of practice and convene a network of practitioners.

Despite the fact that many estuary programs on the West Coast are doing effective conservation, there is not effective coordination among programs and this impedes efficient multi-site action and scaling up of current efforts. Coordination at the requisite scale requires unprecedented leadership and collaboration among stakeholders to promote conservation both inside and outside of traditional protected areas, including on lands and waters where people live and work. As discussed above, the NEP, NERR, and NWR programs have built a solid foundation for management of some West Coast estuaries, but these programs were not designed to work in a multi-site context, and a more unified and comprehensive program with strong leadership and accountability needs to be developed. In addition, agencies do not have a clear framework for the challenge of multi-objective planning at the land-sea interface, and therefore frequently act independently based on plans developed to serve a single facet of this complex environment. Further, many strategies for achieving estuary conservation are already being implemented by a variety of groups across the region, but are focused on single estuaries and not yet well-linked to a regional agenda.

A lead agency should convene management and conservation partners for West Coast estuaries to agree on a regional vision for estuary conservation as well as specific conservation targets, goals, and a framework for planning and policy that will protect estuary processes, functions and ecosystem services. This process should bridge the gaps between traditionally distinct (e.g., terrestrial and marine) stakeholder groups, to resolve upstream issues that impact estuarine and near-shore marine resources. The effort should promote the development of tools for estuary management and planning at a multi-site scale, including catalogues of successful management practices targeted toward specific estuary classes and key threats. Multi-site strategies— especially policy and funding strategies— that will have higher leverage and impact on multiple estuaries should be identified based on shared features and threats among estuaries.

An expanded knowledge/social network of local estuary practitioners that builds off the EBM Network could contribute to the development of a regional vision for estuary conservation on the West Coast. Regular communication among local practitioners at sites up and down the coast would enhance the sharing of knowledge and lessons learned, development of joint projects and proposals, improvement of our understanding of estuary response to restoration, and identification of strategic pilot projects that should be funded.

Goal 2) Achieve a 20% increase in acreage of West Coast estuary catchments, waters, and marshes under conservation—as defined by intact ecological processes, functions and ecosystem services—by 2025 through protection, restoration, and stewardship by public agencies or private conservation agreements.

In order to achieve this goal, total protected acreage within estuary catchments should be increased, estuary zones—from freshwater to terrestrial to marine—should be ecologically intact, and multiple replicates of each estuary type within the region should be protected. Conservation effort should focus on estuary types that are currently under-represented in conservation and estuaries that are resilient to climate change.

A variety of strategic pathways can contribute to the achievement of this goal. First and foremost, the states and federal government should develop dedicated funding streams to support land protection in estuary catchments and to improve protection in estuary waters, and provide significant financial rewards to local governments that implement strong land protection programs focused on estuarine watersheds. In addition, state governments in the region should promote tools—such as land banks, retained use and occupancy agreements, and transfer or purchase of development rights programs—to facilitate voluntary acquisition of private property in estuarine catchments at reduced cost. Important or especially sensitive aquatic areas, such as nursery habitats and migratory corridors, should be designated as protected and managed accordingly.

Focused efforts need to be undertaken with key public and private partners to improve stewardship and management of estuarine ecosystems and their ecological processes and functions. To promote better stewardship and management of public resources at scale, the conservation community should actively participate in and inform multi-site and regional planning and management activities of the agencies that administer the most protected land/waters in the region (USFWS, Forest Service, NOAA, key state agencies). Policies that permit harmful extractive or unsustainable practices—such as clearcut forestry, shoreline hardening, and hydromodification—should be phased out on public lands and waters.

Goal 3) Promote and test incentives, easements, and innovative approaches focused on securing habitat and ecological processes while maintaining profitable human uses on working waterfronts and landscapes.

A large proportion of lands within estuary catchments are both privately owned and in natural land cover. These lands offer tremendous conservation potential if stewarded appropriately through "working landscape" strategies that allow for both economic as well as biodiversity returns. Working lands can contribute to wildlife habitat and migration corridors, aquifer recharge, floodwater retention, and infiltration. Keeping farms, forests, and waterfronts in production helps maintain many of these benefits.

Permanent incentive programs aimed at perpetuating low-impact, sustainable use of estuarine lands and protection and restoration of natural resources should be promoted. Such programs could include direct financial incentives (e.g., grants, subsidized loans, cost-shares, leases); indirect financial incentives (e.g., property or sales tax relief); technical assistance (e.g., referrals, education, training, design assistance programs); and recognition or certification of products and operations. Additional incentives may be needed to encourage some owners of working lands to avoid measures that impair natural processes and functions within estuaries. For example, programs should encourage growers and foresters to increase efforts to prevent discharges of pollutants (including nutrients and sediments), monitor water quality, and implement corrective actions when impairments are found.

Goal 4) Plan and implement ecosystem-based adaption strategies to promote climate change resilience in natural and human communities in estuaries.

Although gradual environmental change is natural, the accelerated climate change we are currently experiencing poses one of the greatest conservation challenges for estuaries situated in developed and working landscapes. Climate resilience has multiple objectives: to protect low-intensity, sustainable human use of the landscape and waterfront while simultaneously protecting estuary services, processes and functions. Agencies and stakeholders should align their planning and implementation to enhance the resilience of estuaries to climate change.

Any program to promote climate resilience requires the development or acquisition of data and tools to understand the problem and its impacts and evaluate alternative solutions. At a minimum, federal and state governments need to support the development of spatial data illustrating the extent of climate impacts, and the natural and socioeconomic resources likely to be impacted. Governments should also take the lead in initiating processes to bring stakeholders together to discuss approaches to dealing with climate impacts, and supply information on the costs and benefits of alternative approaches.

Furthermore, government and private foundations should support pilot projects that demonstrate effective tools and strategies for maintaining intact ecosystem services, processes, and functions in the face of climate change. The concept of "rolling easements"—in which the boundary of the conservation easement would migrate as the location of the shoreline changed—should be explored as a flexible conservation mechanism that would maximize habitat protection over the long term. Government initiatives should be focused on scaling up successful projects for broader application at multiple sites.

The most effective approaches are likely to be those that use natural features to benefit human communities. Natural shoreline features such as wetlands, aquatic vegetation, dunes, and barrier beaches provide large-scale, no-cost services such as flood protection, storm buffering, fisheries habitat, recreational facilities, and water filtration that would be prohibitively expensive to replicate with human-built systems. These habitats tend to migrate landward as sea level rises, and protecting them requires an understanding of their likely future location. Incentives should be created for communities to conserve and manage natural protective features—in their current and future locations—perhaps using mechanisms similar to those used to fund capital projects. The Federal Emergency Management Agency (FEMA) hazard mitigation assistance programs, farm bills, and Coastal Zone Enhancement Grants Programs are examples of existing funding sources that could be used to achieve the multiple objectives of climate resilience.

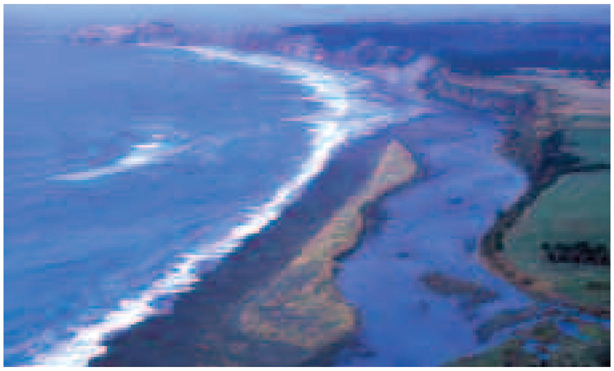
Goal 5) Fund research and pilot projects to improve our understanding of the functions and values of estuaries, critical threats to estuaries, and the conservation effectiveness of restoration and stewardship practices.

Although our understanding of major threats to estuary health, function, and process is sufficient to take action to abate threats and protect ecosystems, there is still much we don't know. In order to improve our understanding of the major threats to estuaries and the benefits estuaries offer to humans, a coordinated approach to funding research, monitoring, and pilot projects in West Coast estuaries should be established. Some priority areas of research might include:

- Develop conceptual models and identify quantitative ranges of variability for key ecological processes in different types of estuaries.
- Identify and map key estuarine habitats that play important roles as nursery habitat for estuarine-dependent marine and anadromous species.
- Validate sea level rise projections, monitor water levels and land subsidence, and model the likely migration pathways of tidal wetlands and other coastal habitats in response to sea level rise.
- Evaluate the impact of ocean acidification to key estuarine habitats and species at various life stages.
- Improve our understanding of the impacts of climate change on high-intensity storm events and resulting patterns of freshwater flows, erosion, and storm surge.
- Track wetland trends at a landscape and regional scale to improve our understanding of overall trends and the key factors contributing to their loss or restoration regionally.
- Improve our understanding of how natural sedimentation and hydrological processes affect land forms in coastal areas, and develop coastal and estuarine sediment budgets.
- Assess ecosystem service values in natural and engineered shorelines and identify best practices for enhancing ecosystem services.

The data compiled for this regional assessment and the approaches recommended here should help to advance estuary conservation on the West Coast in a variety of ways. By better characterizing estuaries by their typology, physical characteristics, threats, ownership, and other factors, practitioners can link their site-specific projects to broader regional efforts. A more integrated approach to land-sea conservation planning will direct more focus on maintaining and restoring ecological processes that govern interactions among various systems, in addition to protecting the habitats and species that are more traditional conservation targets. Classifying estuaries by the natural processes that shape and sustain them helps to identify a representative set of estuaries across the region and determine which threats are most critical to different types of estuaries.

A more systematic, prioritized approach to estuarine conservation on the West Coast can be achieved through the development of a shared definition of success and a shared agenda for achieving it. While conservation proceeds step-by-step through site-based work on protection, stewardship, and restoration, there is an opportunity to develop a more regional approach to identifying multi-site strategies that can advance conservation at many estuaries along the coast. To accomplish this, agencies and other conservation practitioners in all three states will have to come together to engage in collaborative development of strategies.



REFERENCES

Agardy, T., J. Alder, P. Dayton, S. Curran, A. Kitchingman, M. Wilson, A. Catenazzi, J. Restrepo, C. Birkeland, S. Blaber, S. Saifullah, G. Branch, D. Boersma, S. Nixon, P. Dugan, N. Davidson, and C. Vörösmarty (2005) Coastal systems. Chapter 19 in Ecosystems and Human Well-being: Current State and Trends, R. Hassan, R. Scholes, and N. Ash, Eds., Island Press, pp. 513-549. http://www.maweb.org/documents/document.288.aspx.pdf

Bond, M. H., S. A. Hayes, C. V. Hanson, and B. MacFarlane (2008). Marine survival of steelhead (*Oncorhynchus mykiss*) enhanced by a seasonally closed estuary. Canadian Journal of Fisheries and Aquatic Sciences 65, 2242-2252.

Bottom, D. L., K. K. Jones, T. J. Cornwell, A. Gray, and C. A. Simenstad (2005a). Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal and Shelf Science 64, 79-93.

Bottom, D. L., C. A. Simenstad, J. Burke, A. M. Baptista, D. A. Jay, K. K. Jones, E. Casillas, and M. H. Schiewe (2005b). Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. NOAA Technical Memorandum. U.S. Dept. of Commerce.

Brown, J. A. (2006). Using the chemical composition of otoliths to evaluate the nursery role of estuaries for English sole *Pleuronectes vetulus* populations. Marine Ecology Progress Series 306, 269-281.

California Climate Change Center (2009). The impacts of sea level rise on the California coast. http://www.pacinst.org/reports/sea_level_rise/exec_sum.pdf

California Aquaculture Association (CAA) (2001). Editorial: California Aquatic Farming. Available online: www.caa-aqua.org.

Callaway, J. C., V. T. Parker, M. C. Vasey, and L. M. Schile (2007). Emerging issues for the restoration of tidal marsh ecosystems in the context of predicted climate change. Madroño 54(3), 234-248.

Cash, D.W., W. N. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, L. Pritchard, and O. Young (2006): Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World. In: Ecology and Society. vol. 11, no. 2, pp. 8-19.

Climate Change Science Program (2009). Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)]. U.S. Environmental Protection Agency, Washington D.C., USA, 320 pp.

Cohen, A. N., and J. T. Carlton (1995). Nonindigenous aquatic species in a United States estuary: a case study of the biological invasions of the San Francisco Bay and delta. US Fisheries and Wildlife and National Sea Grant College Program. NOAA grant number NA36RG0467.

Conte, F.S. (1990). California aquaculture: Growth keyed to diversity and markets. World Aquaculture 21(3): 33-44.

Copeland, B. J. (1966). Effects of decreased river flow on estuarine ecology. Journal (Water Pollution Control Federation) 38(11), 1831-1839.

Costanza, R., R. D. Arge, R. De Groot et al. (1997). The value of the world's ecosystem services and natural capital. Nature 387, 253-260.

Crain, C. M., B. S. Halpern, M. W. Beck, and C. V. Kappel (2009). Understanding and managing human threats to the coastal marine environment. Annals of the New York Academy of Sciences 1162(The Year in Ecology and Conservation Biology 2009), 39–62.

Dahl, T. E. (2006). Status and trends of wetlands in the conterminous United States 1998 to 2004. U. S. Department of the Interior; Fish and Wildlife Service, Washington, D. C. 112 p.

Dennison, W.C, E.G. Abal, (1999). Moreton Bay study: A scientific basis for the Healthy Waterways Campaign. South East Queensland Regional Water Quality Management Strategy, Brisbane. 246p.

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas (2009). Ocean acidification: the other CO2 problem. Annual Review of Marine Science 1, 169-192.

Dowd, B. M., D. Press, and M. L. Huertos (2008). Agricultural nonpoint source water pollution policy: The case of California's Central Coast. Agriculture, Ecosystems & Environment 128(3), 151–161.

Edgar, G.J., N. S. Barrett, D. J. Graddon, and P. R. Last (2000). The conservation significance of estuaries: a classification of Tasmanian estuaries using ecological, physical, and demographic attributes as a case study. Biological Conservation 92, 383-397.

Engle, V.D., J. C. Kurtz, L. M. Smith, C. Chancy, and P. Bourgeois (2007). A classification of U.S. estuaries based on physical and hydrologic attributes. Environmental Monitoring and Assessment 129, 397-412.

Emmett, R. L., R. Llansó, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping and P. Fishman (2000). Geographic signatures of North American west coast estuaries. Estuaries 26 (6):765—792.

EPA (2006). National Estuary Program coastal condition report. U.S. Environmental Protection Agency, EPA-842/B-06/001, Washington, DC.

EPA (2009). National Estuaries Program habitat loss and degradation. Retrieved August 24, 2010 from http://water.epa.gov/type/oceb/nep/challenges.cfm#habitat

Ferren, W., P. Fiedler, and R. Leidy (1996). Wetlands of California, Part I: History of Wetland Habitat Classification. Madrono 43(1):105-124.

Fresh, K. L. (2006). Juvenile Pacific Salmon in Puget Sound. Technical Report. Puget Sound Nearshore Partnership. Seattle, WA: U.S. Army Corps of Engineers. www.pugetsoundnearshore.org.

Frissell, C. A. (1993). Topology of extinction and endangered of native fishes in the Pacific Northwest and California (U. S. A.). Conservation Biology 7(2), 342-354.

Ganju, N. K.and D. H. Schoellhamer (2010). Decadal-timescale estuarine geomorphic change under future scenarios of climate and sediment supply. Estuaries and Coasts 33, 15-29.

Gee, A. K., K. Wasson, S. L. Shaw, and J. Haskins (2010). Signatures of restoration and management changes in the water quality of a Central California estuary. Estuaries and Coasts 33, 1004-1024.

Gillanders, B. M., K. W. Able, J. A. Brown, D. B. Eggleston, and P. F. Sheridan (2003). Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series 247:281-295.

Gleason, M.G., M.S. Merrifield, C. Cook, A.L. Davenport and R. Shaw (2006). Assessing gaps in marine conservation in California. Frontiers in Ecology and the Environment 4: 249–258.

Grosholz, E. (2002). Ecological and evolutionary consequences of coastal invasions. Trends in Ecology & Evolution 17(1), 22-27.

Grosholz, E. D. and G. M. Ruiz (2009). Multitrophic effects of invasions in marine and estuarine systems. Biological Invasions in Marine Ecosystems 204(4), 305–324.
Groves, C. R., D. B. Jensen, L. L. Valutis, K. H. Redford, M. L. Shaffer, J. M. Scott et al. (2002). Planning for biodiversity conservation: Putting conservation science into practice. BioScience 52, 499-512.

Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa et al. (2008). A global map of human impact on marine ecosystems. Science 319(5865), 948-952.

Halpern, B. S., C. M. Ebert, C. V. Kappel, E. M. P. Madin, F. Micheli, M. Perry, K. A. Selkoe, and S. Walbridge (2009). Global priority areas for incorporating land-sea connections in marine conservation. Conservation Letters 2, 189-196.

Hansen, A. (2008), Trophic interactions at the land-sea interface: importance of food web linkages. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado.

Hansen, A., J. Peterson, J. Ellis, G. Sidnek, and B. Wilson (2008). Terrestrial-Aquatic Linkages: Understanding the Flow of Energy and Nutrients across Ecosystem Boundaries. Department of Fish, Wildlife, and Conservation Biology Colorado State University, Fort Collins, Colorado.

Harley, C. D. G., A. R. Hughes, K. M. Hultgren, B. G. Miner, C. J. B. Sorte, C. S. Thornber, L. F. Rodriguez, L. Tomanek, and S. L Williams (2006). The impacts of climate change in coastal marine systems. Ecology Letters 9, 228-241.

Harris, P. T. and A. D. Heap (2003). Environmental management of clastic coastal depositional environments: Inferences from an Australian geomorphic database. Ocean and Coastal Management 46, 457-478.

Harris, P. T., A. D. Heap, S. M. Bryce, R. Porter-Smith, D. A. Ryan, and D. T. Heggie (2002). Classification of Australian clastic coastal depositional environments based upon a quantitative analysis of wave, tidal, and river power. Journal of Sedimentary Research 72, 858-870.

Hayes, S. A., M. H. Bond, C. V. Hanson, E. V. Freund, J. Smith, E. C. Anderson, A. J. Ammann, and R. B. MacFarlane (2008). Steelhead growth in a small central California watershed: Upstream and estuarine rearing patterns. Transactions of the American Fisheries Society 137, 114-128.

Heap, A., S. Bryce, D. Ryan, L. Radke, C. Smith, R. Smith, P. Harris and D. Heggie (2001). Australian Estuaries & Coastal Waterways: A geoscience perspective for improved and integrated resource management. A Report to the National Land and Water Resources Audit. Theme 7: Ecosystem Health. Australian Geological Survey Organisation, Record 2001/07.

Heller, N.E. and E.S. Zaveleta (2009). Biodiversity Management in the face of climate change. Biological Conservation 142: 14-32.

Howarth, R. W., A. Sharpley, and D. Walker (2002). Sources of nutrient pollution to coastal waters in the United States: implications for achieving coastal water quality goals. Estuaries 25(4b), 656-676.

Hume, T.M., T. Snelder, M. Weatherhead and R. Liefting (2007). A controlling factor approach to estuary classification. Ocean and Coastal Management 50, 905-920.

Interagency Committee for Outdoor Recreation (2005). Toward a coordination strategy for outdoor habitat and recreation land acquisition in Washington State. http://www.rco.wa.gov/documents/hrlcg/LandsFinal.pdf

Jennings, M. D. (2000). Gap analysis: concepts, methods, and recent results. Landscape Ecology 15:5-20.

Josselyn, M., J. Zedler, and T. Griswold (1990). Wetland mitigation along the pacific Coast of the United States. In: Kusler, J. A. & Kentula, M. E (eds). Wetland Creation and Restoration, the Status of the Sciences, Island Press, 3-36 p.

Kennish, M. J. (2002). Environmental threats and environmental future of estuaries. Environmental Conservation 29(01), 78–107.

Kentula, M. E., J. C. Sifneos, J. Good, M. Rylko, and K. Kunz (1992). Trends and patterns in Section 404 permitting requiring compensatory mitigation in Oregon and Washington, USA. Environmental Management 16(1), 109–119.

Kilgore, M.A. and D. R. Blinn (2004). Policy tools to encourage the application of sustainable timber harvesting practices in the United States and Canada. Forest Policy and Economics 6, 111-127.

Kirby, M. X. (2004). Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. Proceedings of the National Academy of Science 101, 13096-13099.

Knottnerus, O. S. (2005). History of human settlement, cultural change and interference with the marine environment. Helgoland Marine Research 99B, 79-88.

Kohm, K.A. and J.F. Franklin (eds.) (1997). Creating a Forestry for the 21st Century: The Science of Ecosystem Management. Island Press, Washington, DC.

Koski, K V. (2009). The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society 14(1): 4. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art4/

Leschine, T. M., B. E. Ferriss, K. P. Bell, K. K. Bartz, S. MacWilliams, M. Pico, and A. K. Bennett (2003). Challenges and strategies for better use of scientific information in the management of coastal estuaries. Estuaries 26(4B), 1189-1204.

Ligon, F., A. Rich, G. Rynearson, D. Thornburgh and W. Trush (1999). Report of the scientific review panel on California forest practice rules and salmonid habitat. Prepared for the Resources Agency of California and the National Marine Fisheries Service, Sacramento, CA.

Lotze, H. K., H. S. Lenihan, B. J. Bourque, R. H. Bradbury, R. G. Cooke, M. C. Kay, S. M. Kidwell, M. X. Kirby, C. H. Peterson, and J. B. C. Jackson (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312, 1806-1809.

Lotze, H. K. and C. Muir (2009). Past lives—piecing together the ecological history of coastal ecosystems can inform today's marine management. Bulletin of the British ecological Society 40, 14-16.

Low, G. (2000). Landscape-scale conservation: a practioner's guide. The Nature Conservancy. Retrieved August 20, 2010 from http://www.conserveonline.org.

Marchetti, M. P., P. B. Moyle and R. Levine (2004). Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. Freshwater Biology 49, 646-661.

Matthews, J. W., and A. G. Endress (2008). Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. Environmental Management 41(1), 130-141.

Mawdsley, J. R., R. O'Malley and D. S. Ojima (2009). A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology 23(5), 1080-1089.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt (2000). Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Depart. Commer., NOAA Technical Memorandum NMFS-NWFSC-42.

Meade, R. H. (1982). Sources, sinks, and storage of river sediment in the Atlantic drainage of the United States. The Journal of Geology, 90(3), 235-252.

Merrifield, M. S., E. Hines, X. Liu and M. W. Beck (2011) Building regional threat-based networks for estuaries in the western United States. PLoS ONE 6(2):e17407. doi:10.1371/journal.pone.0017407

Michener, W. K., E. R. Blood, K. L. Bildstein, M. M. Brinson and L. R. Gardner (1997). Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. Ecological Applications 7(3), 770-801.

Monaco, M. E., R. L. Emmett, D. M. Nelson and S. A. Hinton (1990). Distribution and abundance of fishes and invertebrates in West Coast estuaries, Volume I: Data summaries. ELMR Rep. No. 4. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD, 232 p.

Monaco, M. E., T. A. Lowery and R. L. Emmet (1992). Assemblages of U.S. West Coast estuaries based on distribution of fishes. Journal of Biogeography 19, 251-267.

Moss, A., M. Cox, D. Scheltinga and D. Rissik (2006). Integrated estuary assessment framework. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, technical report 69. Published by the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC) Indooroopilly Sciences Centre 80 Meiers Road Indooroopilly Qld 4068 Australia.

Moyle, P. B., J. A. Israel and S. E. Purdy (2008). Salmon, steelhead, and trout in California: Status of an emblematic fauna. UC Davis Center for Watershed Sciences. Retrieved August 10, 2010 from http://watershed.ucdavis.edu/library.html.

National Park Service (no date). Giacomini Wetland Restoration. Retrieved on Sept. 6, 2010 from: http://www.nps.gov/pore/parkmgmt/planning_giacomini_wrp.htm

National Research Council (2005). Valuing ecosystem services: toward better environmental decision-making. The National Academies Press, Washington D.C.

Nichols, F. H., J. E. Cloern, S. N. Luoma and D. H. Peterson (1986). The modification of an estuary. Science 231, 567-573.

NOAA (March 2008). National Estuaries Restoration Inventory, Total acres restored. Retrieved on Sept. 6, 2010 from: https://neri.noaa.gov/neri/query_main.html

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S. C. Doney, R. A. Feely, A. Gnanadesikan, N. Gruber et al. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437, 681-686.

PacFIN. (2010). All west coast species report species rpt: 2009 commercial landed catch. Retrieved on July 30, 2010 from http://pacfin.psmfc.org/pacfin_pub/data_rpts_pub/all_sp_rpts_pub/r307_woc09.txt.

Peirson, W. L., K. Bishop, D. Van Senden, P. R. Horton and C. A. Adamantidis (2002). Environmental water requirements to maintain estuarine processes. Environmental Flows Initiative Technical Report Number 3, Commonwealth of Australia, Canberra.

Pennifold, M. and J. Davis (2001). Macrofauna and nutrient cycling in the Swan River Estuary, Western Australia: Experimental results. Hydrological Processes 12(13), 2537-2553.

Pritchard, D.W. (1967). What is an estuary: physical viewpoint. In G. H. Lauff (ed), Estuaries. American Association for the Advancement of Science. Washington, D.C.

Ramankutty, N. and A. Foley (1999). Estimating historical changes in land cover: North American croplands from 1850 to 1992, Global Ecology and Biogeography 8(5):381-396.

Rashin E., C. Clishe, A. Loch and J. Bell (2006). Effectiveness of timber harvest practices for controlling sediment related water quality impacts. Journal of American Water Resources Association 42(5):1307-1327.

Ray, G. C. (2005). Connectivities of estuarine fishes to the coastal realm. Estuarine, Coastal and Shelf Science 64, 18-32.

Restore America's Estuaries (N.D.). Habitat loss nationwide. Available at: http://www.estuaries.org/habitat-loss-nationwide.html.

Ritter, A. F., K. Wasson, S. I. Lonhart, R. K. Preisler, A. Woolfolk, K. A. Griffith, S. Connors and K. W. Heiman (2008). Ecological signatures of anthropogenically altered tidal exchange in estuarine ecosystems. Estuaries and Coasts 31, 554-571.

Ryan, D. A, A. D. Heap, L. Radke and D. T. Heggie (2003). Conceptual models of Australia's estuaries and coastal waterways: Applications for coastal resource management. Geoscience Australia Record 2003/09.

Scavia, D., J. Field, D. Boesch, R. Buddemeier, V. Burkett, D. Cayan, D et al. (2002). Climate change impacts on U.S. coastal and marine ecosystems. Estuaries 25(2), 149-164

Schaaf, K. A. and S. R. Broussard (2006). Private forest policy tools: A national survey exploring the American public's perceptions and support. Forest Policy and Economics 9, 316-334.

Sheaves, M., R. Baker and R. Johnston (2006) Marine nurseries and effective juvenile habitats: an alternative view. Marine Ecology Progress Series 318:303–306

Short, F. T. and H. A. Neckles (1999). The effects of global climate change on seagrasses. Aquatic Botany 63, 169-196.

Simenstad, C., D. Reed and M. Ford (2006). When is restoration not?: Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecological Engineering 26(1), 27–39.

Sloan, N. A., K. Vance-Borland and G. C. Ray (2007). Fallen between the cracks: Conservation linking land and sea. Conservation Biology 21(4), 897-898.

Stoms, D. M., F. W. Davis, S. J. Andelman, M. H. Carr, S. D. Gaines, B. S. Halpern et al. (2005). Integrated coastal reserve planning: Making the land-sea connection. Frontiers in Ecology and the Environment 3, 429-436.

Suzuki, N., and D. H. Olson (2007). Options for biodiversity conservation in managed forest landscapes of multiple ownerships in Oregon and Washington, USA. Biodiversity and conservation, 17(5) 1017–1039.

Tallis, H., Z. Ferdana and E. Gray (2008). Linking terrestrial and marine conservation planning and threats analysis. Conservation Biology 22(1), 120-130.

Thorpe, J. E. (1994). Salmonid fishes and the estuarine environment. Estuaries 17(1): 76-93.

Thrush, S, F., J. E. Hewitt, V. J. Cummings, J. I. Ellis, C. Hatton, C., A. Lohrer and A. Norkko (2004). Muddy waters: elevating sediment input to coastal and estuarine habitats. Frontiers in Ecology and the Environment 2(6), 299-306.

Thrush, S. F., J. Halliday, J. E. Hewitt and A. M. Lohrer (2008). The effects of habitat loss, fragmentation, and community homogenization on resilience in estuaries. Ecological Applications 18(1), 12-21.

Townsend, R. S., C. J. Carr, W. M. Sloan and M. H. Imwalle (2009). California tideland and submerged land leasing for conservation purposes. Morrison and Foerster. San Francisco, CA.

Van Dyke, E. and K. Wasson (2005). Historical ecology of a central California estuary: 150 years of habitat change. Estuaries 28, 173-189.

WCGA (2008). West Coast governors agreement on ocean health: Action plan. The Office of the Governors, Washington, Oregon, California USA.

Weinstein, M. P., R. C. Baird, D. O. Conover, M. Gross, J. Keulartz, D. K. Loomis, Z. Naveh, S. B. Peterson, D. J. Reed, E. Roe, R. L. Swanson, J. A. A. Swart, J. M. Teal, R. E. Turner and H. J. van der Windt (2007). Managing coastal resources in the 21st century. Frontiers in Ecology and Environment 5(1), 43-48.

Wenner, E. L. and M. Geist (2001). The National Estuarine Research Reserves Program to monitor and preserve estuarine waters. Coastal Management 29(1), 1-17.

Wilkinson, T. E., E. Wiken, J. Bezaury-Creel, T. Hourigan, T. Agardy, H. Herrmann, L. Janishevski, C. Madden, L. Morgan and M. Padilla (2009). Marine ecoregions of North America. Commission for Environmental Cooperation. Montreal Canada.

Wilson, M.A. and S. Farber (2009). Accounting for ecosystem goods and services in coastal estuaries, in The Economic and Market Value of Coasts and Estuaries: What's At Stake? (Linwood H. Pendleton, ed.).

Yoklavich, M. M., G. M. Cailliet, J. P. Barry, D. A. Ambrose and B. S. Antrim (1991). Temporal and spatial patterns in abundance and diversity of fish assemblages in Elkhorn Slough, California. Estuaries 14(4), 465-480.

Zedler, J. B. (2010). How frequent storms affect wetland vegetation: a preview of climate change impacts. Frontiers in Ecology and the Environment 8: 540-547.

Zedler, J. B. (2000). Progress in wetland restoration ecology. Trends in Ecology & Evolution 15(10), 402–407.

Zedler, J. B. (1996). Coastal mitigation in Southern California: The need for a regional restoration strategy. Ecological Applications 6, 84-93.

Zedler, J. B., J. C. Callaway and G. Sullivan (2001). Declining biodiversity: why species matter and how their functions might be restored in California tidal marsh. BioScience 51(12), 1005-1017.

© Central Coast Wetlands Group at Moss Landing Marine Labs

APPENDIX A Estuaries included in the West Coast Estuary Assessment

Name (north to south)	State	Estuary size (acres)	Catchment size (acres)	Level 2 Type
Oregon and Washington				
Drayton Harbor	WA	2,608.0	59,973	Tidal bay
Lummi Bay	WA	3,968.2	141,614	Tidal bay
Bellingham Bay	WA	51,413.4	214,484	Tidal bay
Padilla Bay	WA	19,278.6	61,182	Tidal bay
Whidbey Basin	WA	156,526.5	592,662	Tidal bay
Admiralty Inlet	WA	80,906.4	166,960	Tidal bay
Discovery Bay	WA	9,158.9	60,802	Tidal bay
Dungeness Bay	WA	2,602.5	229,937	Tidal bay
Sequim Bay	WA	3,353.0	46,905	Tidal bay
Central Puget Sound	WA	210,065.0	833,711	Tidal bay
Hood Canal	WA	78,707.1	680,934	Tidal bay
Pysht River	WA	148.8	29,521	River mouth
Clallam River	WA	15.2	19,980	River mouth
Hoko River	WA	43.3	18,320	River mouth
Waatch River	WA	222.3	11,772	River mouth
Sooes River	WA	122.3	14,524	River mouth
South Puget Sound	WA	107,977.1	757,327	Tidal bay
Quillayute River	WA	141.3	149,207	River mouth
Hoh River	WA	26.4	190,635	River mouth
Queets River	WA	152.4	190,283	River mouth
Raft River	WA	41.8	72,792	River mouth
Quinault River	WA	103.2	108,598	River mouth
Moclips River	WA	19.1	22,890	River mouth
Joe Creek	WA	12.9	22,807	Classic estuary
Copalis River	WA	191.6	25,777	River mouth
Connor Creek	WA	43.1	11,336	Lagoon
Grays Harbor	WA	62,901.9	899,282	Classic estuary

Name (north to south)	State	Estuary size (acres)	Catchment size (acres)	Level 2 Type
Willapa Bay	OR	96,589.4	682,427	Classic estuary
Columbia River	OR	108,871.1	1,013,940	River mouth
Necanicum River	OR	248.4	84,245	Classic estuary
Nehalem River	OR	1,961.5	132,390	River mouth
Tillamook Bay	OR	9,847.6	359,668	Classic estuary
Netarts Bay	OR	2,536.7	16,325	Classic estuary
Sand Lake	OR	1,068.5	15,934	Lagoon
Nestucca Bay	OR	946.9	204,262	Classic estuary
Salmon River	OR	689.3	47,767	River mouth
Siletz Bay	OR	1,711.8	122,438	River mouth
Yaquina Bay	OR	4,193.5	50,673	Classic estuary
Alsea Bay	OR	2,649.5	144,258	Classic estuary
Siuslaw River	OR	2,879.4	152,653	River mouth
Umpqua River	OR	6,221.4	209,210	River mouth
Coos Bay	OR	12,516.8	151,614	Classic estuary
Coquille River	OR	1,040.0	111,667	River mouth
Sixes River	OR	15.6	86,267	River mouth
Elk River	OR	33.9	58,398	River mouth
Rogue River	OR	699.4	82,717	River mouth
Pistol River	OR	79.1	67,285	River mouth
Chetco River	OR	170.5	225,228	River mouth
Winchuck River	OR	31.7	45,653	River mouth
Central and Northern California				
Tillas Slough	CA	460.2	88,778	River mouth
Lake Earl	CA	2,254.7	32,390	Lagoon
Wilson Creek	CA	22.8	17,125	Lagoon
Klamath River	CA	567.9	68,060	River mouth
Redwood Creek	CA	53.8	180,845	River mouth
Freshwater Lagoon	CA	242.0	24,329	Lagoon
Stone Lagoon	CA	568.7	24,329	Lagoon
Big Lagoon	CA	1,243.8	24,329	Lagoon
Little River	CA	21.1	28,661	River mouth
Mad River	CA	158.7	182,915	River mouth

Name (north to south)	State	Estuary size (acres)	Catchment size (acres)	Level 2 Type
Humboldt Bay	CA	17,615.5	141,367	Classic estuary
Eel River Estuary	CA	2,512.4	62,038	River mouth
Bear River	CA	12.6	52,980	River mouth
Mattole River	CA	99.7	189,805	River mouth
Tenmile River	CA	43.7	76,570	River mouth
Pudding Creek	CA	11.9	20,740	River mouth
Noyo River	CA	34.0	72,524	River mouth
Big River	CA	84.2	116,079	River mouth
Navarro River	CA	29.9	201,614	River mouth
Elk Creek	CA	3.8	17,707	Lagoon
Alder Creek	CA	7.0	18,635	Lagoon
Garcia River	CA	26.9	73,045	River mouth
Gualala River	CA	52.4	191,205	River mouth
Russian River	CA	287.0	94,495	River mouth
Salmon Creek	CA	21.1	22,459	Lagoon
Estero Americano	CA	129.9	24,277	River mouth
Bodega Bay	CA	915.1	7,253	Classic estuary
Tomales Bay	CA	7,526.7	67,287	Tidal bay
Abbotts Lagoon	CA	214.8	10,833	Lagoon
Bolinas Lagoon	CA	1,111.1	12,511	Lagoon
Drakes Estero	CA	2,485.0	21,400	Lagoon
Tenessee Valley Creek	CA	2.4	12,786	Lagoon
Rodeo Lagoon	CA	50.2	12,786	Lagoon
San Francisco Bay - San Pablo Bay	CA	85,771.4	431,308	Classic estuary
San Francisco Bay - Suisun Bay / Carquinez Straight	CA	47,766.8	720,355	Classic estuary
San Francisco Bay - Central Bay	CA	105,317.8	131,240	Classic estuary
San Francisco Bay - South Bay	CA	79,061.5	857,893	Classic estuary
Leon Arroyo	CA	2.9	18,393	Lagoon
San Gregorio Creek	CA	9.1	20,078	Lagoon
Pescadero Creek	CA	36.0	51,737	Lagoon

Name (north to south)	State	Estuary size (acres)	Catchment size (acres)	Level 2 Type
Santa Cruz Harbor	CA	38.8	58,122	Tidal bay
San Lorenzo River	CA	22.1	87,171	River mouth
Waddell Creek	CA	3.5	15,312	Lagoon
Watsonville Slough	CA	121.9	117,972	River mouth
McClusky Slough	CA	44.3	46,083	Lagoon
Elkhorn Slough	CA	1,978.3	46,083	Lagoon
Scott Creek	CA	6.6	19,113	Lagoon
Salinas River	CA	423.5	265,669	River mouth
Carmel River	CA	39.2	162,472	River mouth
Little Sur River	CA	34.9	25,680	River mouth
Big Sur River	CA	6.9	37,379	River mouth
San Carpoforo Creek	CA	42.4	22,835	Lagoon
Arroyo de la Cruz	CA	6.4	15,877	Lagoon
Arroyo del Puerto	CA	0.5	29,425	Lagoon
Arroyo Laguna	CA	5.7	29,425	Lagoon
Pico Creek	CA	1.9	29,425	Lagoon
San Simeon Creek	CA	7.0	20,570	Lagoon
Santa Rosa Creek	CA	4.8	15,684	Lagoon
Cayucos Creek	CA	1.0	12,286	Lagoon
Old Creek	CA	7.8	13,154	Lagoon
Toro Creek	CA	5.6	14,425	Lagoon
Villa Creek	CA	3.0	12,214	Lagoon
Morro Bay	CA	2,544.5	49,551	Classic estuary
Pismo Creek	CA	11.4	32,875	Lagoon
San Luis Obispo Creek	CA	16.0	38,662	Lagoon
Oso Flaco Creek	CA	59.8	27,854	Lagoon
Santa Maria River	CA	122.5	59,897	River mouth
Santa Ynez River	CA	366.9	102,941	River mouth
San Antonio Creek	CA	13.5	97,651	Lagoon
Southern California				
Marina del Rey - Ballona Creek	CA	590.7	112,946	Tidal bay
Anaheim Bay - Bolsa Chica Lagoon	CA	1,511.6	57,005	Lagoon

Name (north to south)	State	Estuary size (acres)	Catchment size (acres)	Level 2 Type
Malibu Lagoon	CA	21.2	70,127	Lagoon
Alamitos Bay	CA	258.3	210,830	Tidal bay
Santa Ana River	CA	236.8	67,152	Tidal bay
Los Angeles River	CA	380.3	135,084	Tidal bay
Newport Bay	CA	1,234.8	102,526	Classic estuary
Long Beach Harbor	CA	2,137.4	39,211	Tidal bay
El Estero - Carpinteria Marsh	CA	172.9	32,517	Lagoon
Ventura River	CA	15.3	144,350	River mouth
Dana Point Harbor	CA	162.8	40,116	Tidal bay
Santa Clara River	CA	131.2	113,906	River mouth
McGrath Lake	CA	10.8	18,503	Lagoon
Oramond Beach	CA	33.5	18,503	Lagoon
Mugu Lagoon	CA	1,834.2	51,424	Lagoon
Santa Margarita Marsh	CA	297.4	99,798	River mouth
Del Mar Boat Basin	CA	214.1	993	Tidal bay
Goleta Slough	CA	190.2	17,657	Lagoon
Agua Hedionda Creek	CA	337.8	18,987	Classic estuary
Devereux Lagoon	CA	39.5	27,366	Lagoon
Batiquitos Lagoon	CA	391.6	34,246	Lagoon
San Elijo Lagoon	CA	321.8	54,248	Lagoon
San Dieguito Lagoon	CA	44.7	50,017	Lagoon
Los Penasquitos Marsh	CA	298.1	60,258	Lagoon
Mission Bay	CA	2,238.1	143,132	Tidal bay
San Diego Bay	CA	11,414.5	232,044	Tidal bay
Tijuana Estuary	CA	568.1	29,357	Classic estuary

APPENDIX B Spatial data layers in the West Coast Estuary Database (www.tnccmaps.org/estuaries)

© Central Coast Wetlands Group at Moss Landing Marine Labs

Variable	Alias	Description	Source(s)
Geographic characteristics			
Unique ID	eid	Unique id for estuary Auto	calculate in GIS
Name	fname	Name of estuary	USFWS National Wetlands Inventory, USGS
Acres of estuary	estuary_ac	Acres of estuary catchment	USFWS National Wetlands Inventory, USGS
Acres of catchment	catchment_ac	Acres of estuary catchment	USGS National Hydrologic Dataset
Size class	size_desc	Size category (Very small, Small, Large, Mega)	TNC
Type	level2_desc	Level 2 category (Classic estuary, Lagoon, River mouth, Tidal bay)	TNC et al.
Terrestrial ecoregion	t_ecoregion	The terrestrial ecoregion that the estuary is associated with	TNC
Marine ecoregion	level1_desc	The marine ecoregion that the estuary is associated with	TNC
State	State	The state that the estuary is in (California, Oregon, Washington)	Esri
Management and land use			
Protection	pct_gap123	The percent of the estuary catchment in "protected" (Gap 1 2 or 3) lands	USGS Protected Areas Database v 1.1
Marine management	pct_mgmt_m	The percent of open water and marsh in a marine managed area	NOAA MPA Inventory Database
Private land	pct_prvt	The percent of catchment in private lands	USGS Protected Areas Database v 1.1
Natural land cover	pct_nat	The percent of catchment in natural land cover	NOAA Coastal Change and Analysis Program
Forest land cover	pct_for	The percent of catchment in forested land cover	NOAA Coastal Change and Analysis Program
Agriculture	pct_agr	The percent of catchment in agricultural land use	NOAA Coastal Change and Analysis Program
Development	pct_dev	The percent of the catchment in developed land use	NOAA Coastal Change and Analysis Program

Variable	Alias	Description	Source(s)
Habitats and species			
Wetlands	sum_wet_ac total amount (acres) of estuarine wetland-	types (emergent, forested, and scrub shrub wetland, aquatic beds)	NOAA Coastal Change and Analysis Program
Floodplain habitat	sum_floodhab_ac	total amount (acres) of natuaral land cover within FEMA 100 and 500 year floodplains in catchment	
Species richness	spp_rich	Number of unique species occurences in catchment	Natural Heritage Programs (CA,OR,WA)
Birds	count_iba	Number of Audubon Important Bird Areas within the catchment	Audubon Important Bird Areas
Marine mammals	sum_pinn	Total number of marine mammal rookeries and haulouts	
Coho	coho	Maximum value of Coho Salmon Stronghold Index (SSI) in catchment	Wild Salmon Center, TNC
Fall chinook	f_chinook	Maximum value of fall Chinook SSI in catchment	Wild Salmon Center, TNC
Spring / summer steelhead	sp_su_steelhead	Maximum value of the spring and summer Steelhead SSI in catchment	Wild Salmon Center, TNC
Summer steelhead	su_steelhead	Maximum value of summer Steelhead SSI in catchment	Wild Salmon Center, TNC
Winter steelhead	w_steelhead	Maximum value of winter steelhead SSI in catchment	Wild Salmon Center, TNC
Human uses and sea level rise			
Shoreline armoring	pct_armor	Percent of estuary shoreline that is armored	NOAA Environmental Sensitivity Index
Marinas and Ports	marina_portfac	Number of marinas and port facilities	US ACOE Port facilities
Incompatible forestry	ccut	Total acres of clear-cutting in the catchment	NOAA Coastal Change and Analysis Program
Toxics	tri	Number of sites from Toxics Release Inventory	US EPA Toxics Release Inventory
Dams	dam	Number of dams in the catchment	StreamNet, Dept of Water Res., ACOE
Nutrients	nutr	Total length of nutrient listed (303d) waterways in the catchment	US EPA 303d listings

Variable	Alias	Description	Source(s)
Sediment	sedi	Total length of sediment listed (303d) waterways in the catchment	US EPA 303d listings
Temperature	temp	Total length of temperature listed (303d) waterways in the catchment	US EPA 303d listings
Coliform	coli	Total length of coliform listed (303d) waterways in the catchment	US EPA 303d listings
Wetland migration area (m)	m_acres	Total acres of wetland migration area (2000 2100) assuming a 1.4m sea level rise Calif. only	Pacific Institute
Protected natural lands in "m"	pct_npro_in_m	percent of "m" in protected natural areas California only	Pacific Institute
Private lands in "m"	pct_nprv_in_m	percent of "m" in private natural areas California only	Pacific Institute

FSC LOGO IN WHITE

The Nature Conservancy

Protecting nature. Preserving life.™