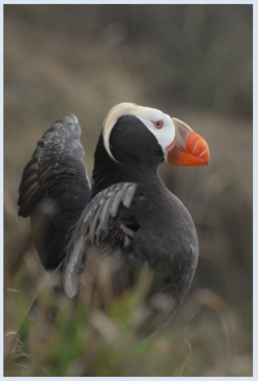
STATE OF THE WASHINGTON COAST
Ecology, Management, and Research Priorities





Washington Department of Fish & Wildlife

Editors

Elizabeth Skewgar[1] and Scott F. Pearson[1]

Contributing authors

Elizabeth Skewgar[1], Megan Dethier[2], Scott F. Pearson[1], Gretchen Blatz[1], Kenneth I. Warheit[1], and Michele Culver[1]

Reviewers (in alphabetical order)

Liam Antrim[3], Rich Carlson[4], Jennifer Hennessey[5], Thomas F. Mumford[6], Charles A. Simenstad[7], Joanna Smith[8], and Barry Troutman[1]

[1]*Washington Department of Fish and Wildlife*

[2]*University of Washington Friday Harbor Labs*

[3]*Olympic Coast National Marine Sanctuary*

[4]*U.S. Fish and Wildlife Service*

[5]*Washington Department of Ecology*

[6]*Washington Department of Natural Resources*

[7]*University of Washington*

[8]*The Nature Conservancy*

Cover photo credits

Top row: Steller sea lions (*Eumetopias jubatus*) by Pete Hodum; Kalaloch Creek by Barry Troutman

Middle row: double-crested cormorant (*Phalacrocorax auritus*) colony off Tatoosh Island, tufted puffin (*Fratercula cirrhata*) by Peter Hodum; sea anemones (order Actiniaria) by Barry Troutman

Bottom row: Black rockfish (*Sebastes melanops*) with red sea urchins (*Strongylocentrotus franciscanus*), vermillion rockfish (*Sebastes miniatus*) by Wayne Palsson, Washington Department of Fish and Wildlife; kelp (order Laminariales) by Peter Hodum

Suggested citation

Skewgar, E. and S.F. Pearson (Eds.). 2011. *State of the Washington Coast: Ecology, Management, and Research Priorities*. Washington Department of Fish and Wildlife, Olympia, Washington.

Table of Contents

List of Figures

List of Tables

.

Preface

On December 22, 1988, the Nestucca barge was struck by the Ocean Service tug at the mouth of Grays Harbor, Washington, resulting in the release of approximately 231,000 gallons of No. 6 heavy fuel oil into the Pacific Ocean off the southwest coast of the state of Washington. The spilled oil spread from the accident site at the mouth of Grays Harbor, both into the harbor and along the outer coast from Oregon to Vancouver Island, British Columbia. In total, approximately 175 km of Washington's shoreline north of Grays Harbor were affected, including the Olympic National Park, five National Wildlife Refuges, and the area now comprising the Olympic Coast National Marine Sanctuary (Momot 1995). In January 1991, the responsible parties reached a settlement agreement with the State of Washington (U.S.D.C., District of Oregon, January 24, 1991, Civil No. 89-609-RE, 1991 AMC 1242), which included funding to produce this document, the *State of the Washington Coast*.

This document characterizes the ecological communities of the outer coast and identifies priority monitoring and research needs concerning these communities. Better knowledge of these ecological communities can be used to assess and restore oil spill impacts to the environment. The document also describes other stressors that may act cumulatively to affect the impact of a spill on particular habitats or species and describe current approaches to monitor and manage coastal stressors. This document could contribute to periodic revisions of the state's plans for oil spill prevention and response, and is also intended to be used by natural resource managers and researchers to help prioritize scientific research, monitoring, and management activities, and to identify potential partnerships for coordinated research and management. The information provided here about the physical and ecological geography of the Washington coast was assembled from the scientific literature, enhanced by contributions from Washington State resource management agencies and other contributors.

As a companion to the *State of the Washington Coast* report, experts in state and federal agencies, academia, and private organizations contributed accounts that describe certain species of the outer coast. We hope that these documents will be expanded across more species and frequently updated to reflect new research findings.

As this report was being drafted, we heard the sobering news of the Macondo (Deepwater Horizon) blowout and oil spill in the Gulf of Mexico during April-July 2010, more than two decades after the *Nestucca* spill. The disaster underscored the need to dedicate adequate resources to inventory, protect, and restore the precious resources of the coastal zone that so many living things, including humans, depend on for their individual sustenance and the well-being of their communities.

Executive Summary

The *State of the Washington Coast* report describes the physical habitats and ecological communities of Washington's outer coast between Cape Flattery and the mouth of the Columbia River. The ShoreZone mapping system is used to characterize the near shore physical habitats that determine the extent of biological communities. These habitats and communities are affected by physical processes, such as currents, tides, and climate. They are also affected by stressors which humans cause or may contribute to, such as oil pollution, climate change, harvest and disturbance, non-native invasive species, habitat loss, and harmful algal blooms. Washington State has developed a variety of mechansims to manage the outer coast, including governmental coordination, marine protected areas, species and habitat monitoring and management, environmental monitoring, oil spill response, and ecological restoration. However, current approaches are not adequate to balance the multiple needs and increasing pressures of human uses of coastal natural resources. Two related areas for increased research are ecosystem-based management and marine spatial planning. Both will require new administrative mechanisms and scientific data on key indicators of the well-being of coastal natural resources and human communities.

Introduction

The outer coast of Washington State lies within the temperate California Current Large Marine Ecosystem (Sherman 1995), the part of the northeast Pacific Ocean which borders southern British Columbia, Canada, the U.S. states of Washington, Oregon, California, as well as Baja California, Mexico. Washington's outer coast runs for over 250 km from Cape Flattery to the Columbia River (Figure 1). The northern shoreline from Cape Flattery south to Point Grenville is characterized by long stretches of rugged, rocky headlands and cliffs, high wave energy, and high species diversity (Strickland and Chasan 1989). This rocky habitat gradually merges with more gravel and sand beaches, alternating with the rocky headlands of the mid-coastline. The southern coast from Point Grenville south to the Columbia River is characterized by long stretches of sand beaches, and includes Washington's three largest coastal estuaries: Grays Harbor, Willapa Bay and the Columbia River (Strickland and Chasan 1989). The diversity of physical habitats contributes to the richness and variety of ecological communities, which in turn sustain human communities along the coast (Washington State Ocean Policy Work Group 2006).

This document contains four sections. The "Introduction" describes the scope of the document and details how Washington State agencies classify and map coastal habitats. The second section, "Ecology of the Washington Coast," describes physical habitats and their associated ecological communities, emphasizing intertidal (littoral) habitats found between the low and high tide lines. It also covers the pelagic zone and the sea floor below the low tide line, the subtidal (sublittoral) zone. We do not attempt to comprehensively cover the terrestrial habitats adjacent to the shore (except a brief discussion for sand dunes), nor do we address oceanic habitats beyond the edge of the continental shelf or the deeper benthic zones (except for corals). We were not able to comprehensively cover tidal freshwater ecosystems, such as freshwater scrub-shrub or forested areas, although we do touch on tidal surge areas in the Chehalis River surge plain. We do not include river drainages except to note high areas of productivity at the mouths of major rivers and to identify anadromous fish spawning rivers, but note that terrestrial activities are known to to have strong effects on marine habitats (Halpern et al. 2008). We include information on how key threats to the coast affect each ecological habitat in this section. The third section, "Management of the Washington Coast," explains the approaches currently in place to manage coastal ecosystem. The final section, "Research Priorities for the Washington Coast," identifies priority areas for for research and monitoring to increase understanding of coastal stressors (including oil spills) and improve management responses.

Following the conventions for defining the outer coast established by Washington's Coastal Zone Management Program (Swanson et al. 2001), this document covers a geographical area bounded by Cape Flattery in the north and the mouth of the Columbia River in the south. The geographical area complements the geographic scope of the work of the Puget Sound Partnership (with seven action areas that span marine areas and terrestrial watersheds of Puget Sound, the Strait of Juan de Fuca, and Whidbey and San Juan Islands) and Columbia River Estuary management activities.

Coastal habitats

A habitat is any physical environment where an organinism, or a community of organisms, makes its home. The term is also used to describe the set of biological and physical characteristics that define limits of where a particular species or community can live. Terrestrial habitats are often defined by the climate, soils, and characteristic plant communities that form the physical structure, for example a dry-mesic montane mixed conifer forest (Washington Department of Natural Resources 2007). Marine habitats are usually classified by physical characteristics of the environment, because physical parameters often limit the distributions of marine organisms within a limited "envelope" of physical gradients (Dethier 1992). Geological variation, oceanographic processes (such as wave energy, upwelling, and riverine freshwater inputs), and their interactions form a geomorphically complex shoreline. Understanding the spatial distribution of physical habitats provides insights into the distribution of many species and communities, which have a strong association with a specific physical habitat type. In some cases, the physical structure that defines the habitat is created by a particular species, forming a biogenic habitat such as an eelgrass meadow, oyster reef, kelp forest, or coral reef.

Coastal habitat classification and mapping

Any effort to survey and map ecosystems – for species and habitat inventories, planning conservation activities, mapping harvestable resources, or quantifying sensitivity to human impacts – is best served by a consistent classification system using common terminology. Terrestrial ecologists in the United States and Canada established systematic habitat classification systems in the 1970s and later, but in the marine realm such systems have been developed more recently. Like terrestrial classification systems, marine classifications systems focus on distinguishable physical habitats and the natural communities associated with them, and such classification systems have generally proven effective at predicting the relationship between abiotic parameters and biotic elements (Bourgeron 1988). Until recently, data on the location and abundance of abiotic and biotic coastal resources for the entire marine and estuarine shoreline of Washington State did not provide the resolution needed to classify shoreline habitats. Older shoreline maps for Washington that covered the entire coast include those in the Coastal Zone Atlas (by Youngmann over 1977-1980), the Department of Ecology's *Coastal Sensitive Areas* habitat maps (Washington Department of Ecology 1992), and biological resource maps produced jointly by the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service.

One early non-terrestrial classification system, the National Wetland Inventory System, used parameters such as "system" (marine versus estuarine), "substratum type," "water depth," "water chemistry," "water regime," "dominance level," and "diagnostic species" to define variations in wetland habitats (Cowardin et al. 1979). Dethier (1990, 1992) adapted the National Wetland Inventory System for marine and estuarine ecosystems in Washington and improved predictions of corresponding species assemblages by examining a greater number of physical parameters. For example, Dethier's system included exposure (wave and current energy), which is considered one of the most critical factors controlling distributions of marine organisms, especially plants and other sessile species (see Lewis 1964; Dayton 1975). The Dethier classification system described 96 habitats in the intertidal and subtidal zones of marine and estuarine environments, identifying differences in substrate, wave exposure, depth, salinity, and dominant species. However, the Dethier system does not have an associated mapping methodology.

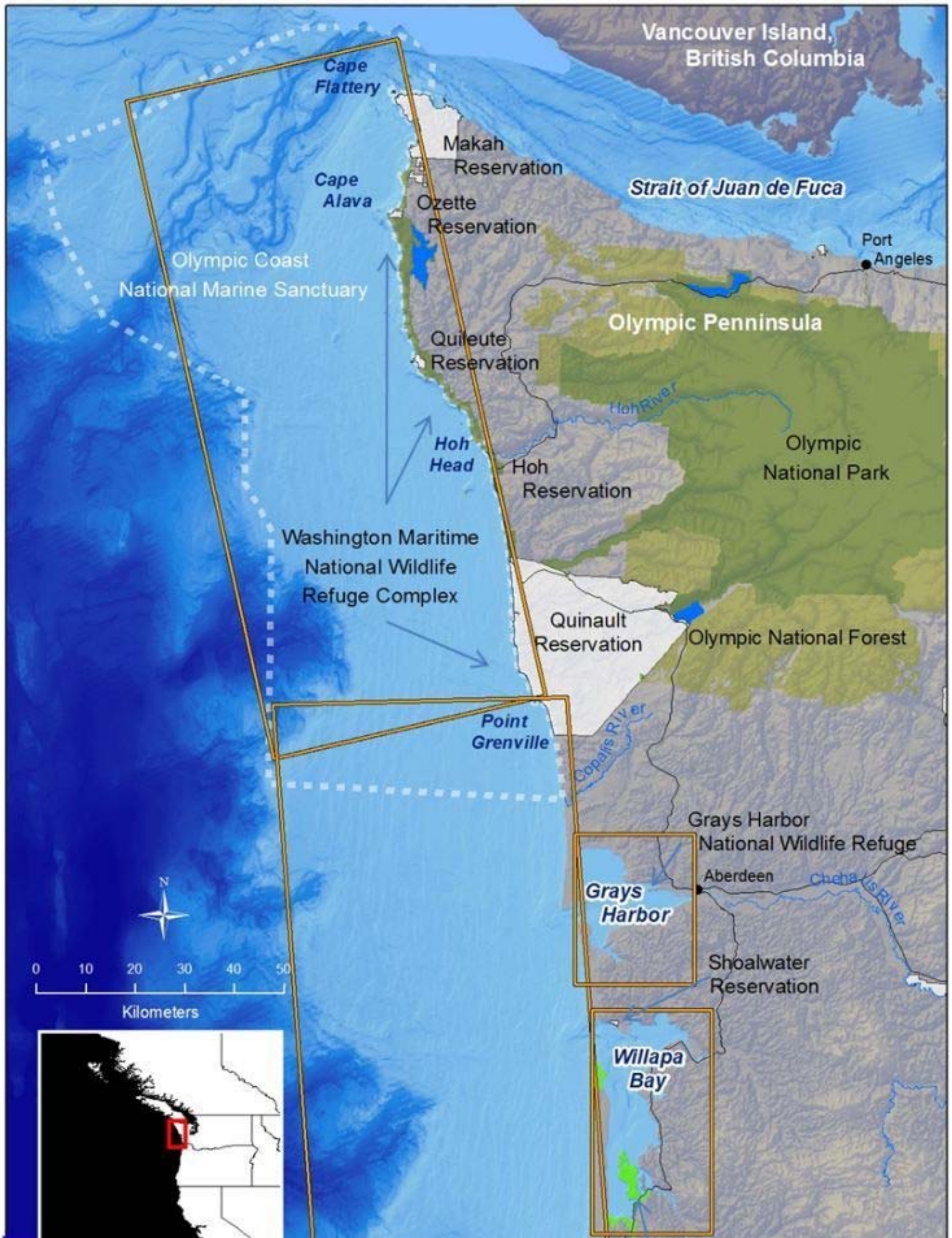


FIGURE 1: MAP OF THE OUTER WASHINGTON STATE COAST. FOUR AREAS OF INTEREST (NORTH OUTER COAST, SOUTH OUTER COAST, GRAYS HARBOR, AND WILLAPA BAY) ARE INDICATED WITH RECTANGLES. GRAPHIC IS COURTESY OF S. SNYDER AND S.F. PEARSON, WASHINGTON DEPARTMENT OF FISH AND WILDLIFE.

A system was needed to combine a habitat classification system with a higher-resolution mapping protocol. The British Columbia (BC) Physical ShoreZone mapping system and the BC Biological ShoreZone mapping system (Harper et al. 1991; Howes et al. 1994; Searing and Frith 1995) emphasized the geophysical control of marine habitats and communities and focused on shoreline morphology, salinity, wave energy, and substrate type. While originally designed to predict the sensitivity of different habitat types to oil spills, it rapidly became clear that this system also had predictive power about biotic communities present on shorelines. It was designed so that data on habitats could be gathered from the air over a large spatial scale. The BC ShoreZone classes differ from the Dethier habitats primarily in emphasizing shore-form descriptors and in not including an exposure qualifier in the class name itself; for example, the same beach on the outer coast might be classified as “rock cliff” by BC ShoreZone, but as “marine intertidal rock: exposed” in the Dethier system. The BC ShoreZone system also subdivides its shore-form descriptors even further, with types of rock specified as “rock platform with wide gravel beach” versus “rock ramp with wide gravel beach,” depending on the slope of the rocky area. Thus, a single BC Shorezone class can be used to describe multiple types of substrate that may occur across the elevational extent of a section of shoreline from low water to the splash zone. From a biological point of view, these classes would likely be very similar, but they might differ in residence time of spilled oil.

The Washington State ShoreZone Inventory (Nearshore Habitat Program 2001), which is based on the BC ShoreZone system, comprehensively catalogued the intertidal habitat types of the saltwater shoreline of Washington State in 2001. Washington’s ShoreZone system features 34 habitats. Video imagery was collected “from the window of a helicopter traveling at 60 mph and 300 feet above the ground” at low tide (Berry et al. 2001). A biologist onboard recorded commentary on the occurrence of conspicuous plants, algae and invertebrate populations. The imagery was used in conjunction with onboard audio characterization from a geomorphologist to divide the shoreline into homogenous segments based on geomorphology. The resulting database includes shoreline morphology, substrate, wave exposure, and visible macrobiota for each segment, providing baseline data on ecosystem elements and processes in the marine environment (Berry et al. 2001).

This report uses the habitat classification system and mapping data from the Washington State ShoreZone project to describe intertidal areas. We include only those ShoreZone categories present on the outer coast and its estuaries, and in the text we frequently condense highly similar categories, as shown in Table 1 and Figure 2. In the next section, we refer to four major physical habitats: estuaries, sandy beaches (non-estuarine sediment substrate), mixed substrates, and rocky shores. The latter three correspond to general substrate types from the ShoreZone categories, but the estuarine habitat was defined geographically by visually selecting the segments pertaining to Willapa Bay and Grays Harbor in a geographic information system. (An alternative method would be to form categories based on the wave exposure attribute of each segment.) Some small but biologically important estuarine habitats associated with river mouths are included in the outer coast data. Descriptive biological information comes primarily from Dethier (1990) and Johnson and O’Neil (2001). We also discuss biogenic habitats that occur within these major physical habitats and in the deep benthos.

ShoreZone can be used to affordably map large areas because it treats the shoreline as a linear feature. This approach is successful for regional-scale data along narrow shorelines. However, its usefulness is limited for characterizing areas with broad intertidal zones, where a single category for a length of shoreline does not adequately describe the abundance and distribution of habitats. In areas with extensive intertidal flats, the mapping system includes polygons digitized from navigational charts, but these areal estimates do not cover the entire extent of each habitat type and should be considered very approximate. Polygon data were not used in this report.

High-resolution mapping activity beyond the intertidal is much more limited. The Olympic Coast National Marine Sanctuary launched a benthic habitat mapping program in 2002, gathering data on bathymetry and substrate types using multibeam and sidescan sonar and other methods. As of 2010, high resolution data are available for approximately 25% of the sanctuary seafloor, and very little high resolution data are available for the seafloor south of Point Grenville, leaving large areas of habitat inadequately mapped.

TABLE 1: LINEAR EXTENT (KM) OF SHOREZONE HABITAT TYPES ON WASHINGTON'S PACIFIC COAST. DATA WERE OBTAINED FROM THE SHOREZONE DATABASE (NEARSHORE HABITAT PROGRAM 2001) AND DIVIDED INTO FOUR GEOGRAPHICAL AREAS BETWEEN CAPE FLATTERY AND THE COLUMBIA RIVER.

Linear extent of shoreline habitats (km)								
	North Outer Coast	South Outer Coast	Outer Coast Total	Grays Harbor	Willapa Bay	Estuary Total	Habitat Totals	Percentage of Total shoreline
Sand and gravel flat or fan	8.6		8.6		4.4	4.4	13.0	1
Sand and gravel beach	2.2		2.2	3.1	4.3	7.4	9.5	1
Sand beach	6.6		6.6	10.3	19.0	29.3	36.0	4
Sand flat	52.6	109.0	161.5	10.0	18.4	28.4	189.9	20
Mud flat			0.0	18.2	3.7	21.9	21.9	2
Organics/fines	22.1	9.0	31.1	112.2	299.9	412.1	443.3	46
Sediment	92.1	118.0	210.1	153.8	349.8	503.6	713.6	74
Cliff with gravel beach	6.9		6.9				6.9	1
Cliff with gravel and sand beach	15.4		15.4				15.4	2
Cliff with sand beach	2.0		2.0				2.0	<0.5
Ramp with sand beach	0.5	1.8	2.3				2.3	<0.5
Platform with gravel beach	9.8		9.8		0.5	0.5	10.2	1
Platform with gravel and sand beach	55.2		55.2				55.2	6
Platform with sand beach	26.5		26.5				26.5	3
Mixed substrates	116.2	1.8	118.0	0.0	0.5	0.5	118.5	12
Rock cliff	47.1		47.1	1.2	24.4	25.7	72.8	8
Rock ramp	9.6		9.6				9.6	1
Rock platform	3.2		3.2				3.2	<0.5
Rocky shores	59.9	0.0	59.9	1.2	24.4	25.7	85.6	9
Constructed		5.2	5.2	26.5	15.9	42.5	47.6	5
Anthropogenic	0.0	5.2	5.2	26.5	15.9	42.5	47.6	5
Geographical Totals	268.2	124.9	393.1	181.5	390.6	572.2	965.3	100

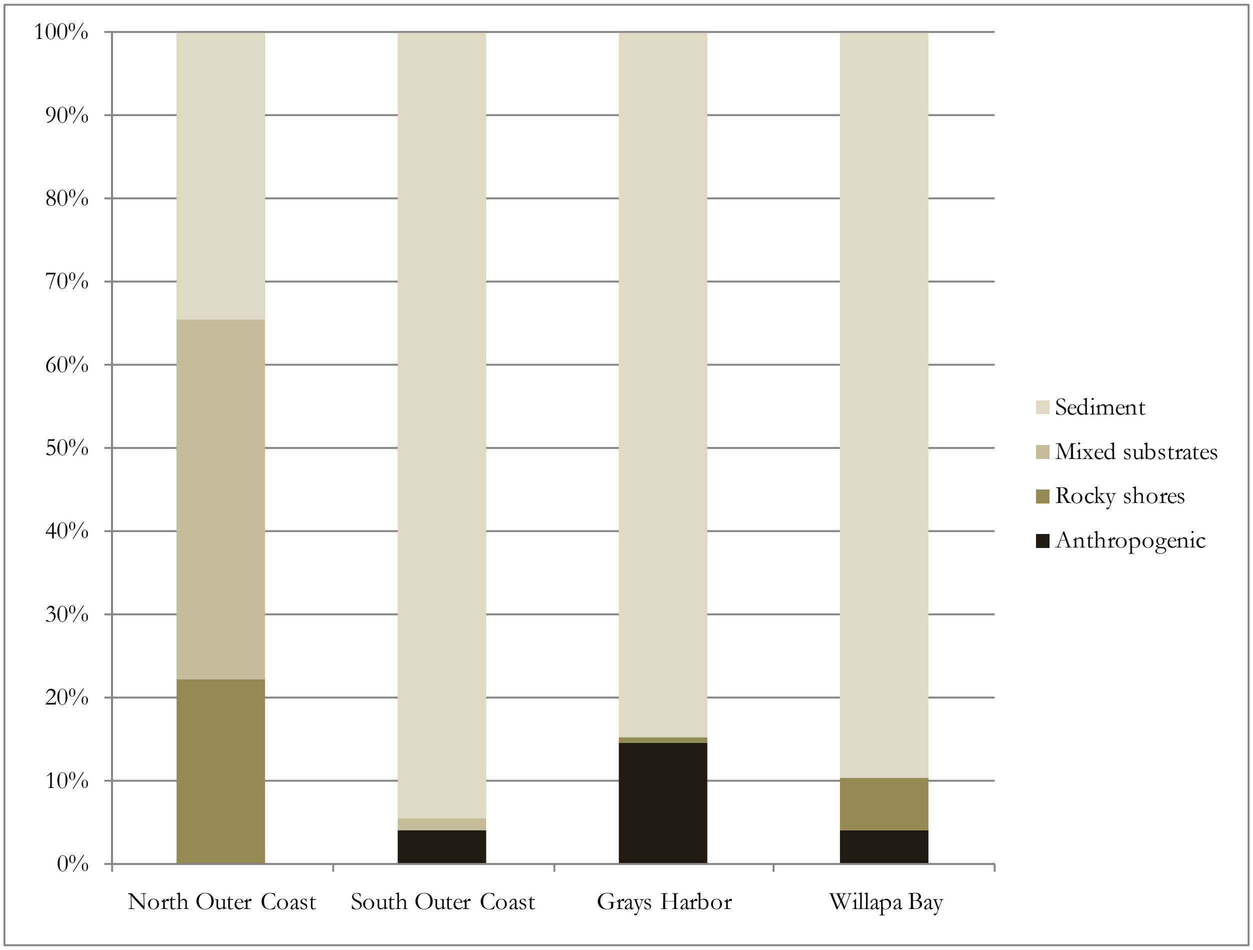


FIGURE 2: PERCENTAGE OF LINEAR EXTENT OF MAJOR HABITAT TYPES ON WASHINGTON'S PACIFIC COAST. DATA WERE OBTAINED FROM THE SHOREZONE DATABASE (NEARSHORE HABITAT PROGRAM 2001) PER TABLE 1.

I. Ecology of the Washington coast

Physical processes

Habitats vary along the coast both with physical substrates and with gradients in water column physical energy, temperature, depth, and salinity. Physical processes vary over short and long time scales, with daily tides and multi-day upwelling-downwelling events, seasonal shifts in current patterns, and multi-year patterns across the entire Pacific Ocean (Hickey and Banas 2003). Human activities also affect coastal habitats, but distinguishing anthropogenic changes is made much more difficult by the natural variation in the system. The impact of human activities depends on interactions with natural variation in multiple physical parameters (Ray and McCormick-Ray 2004).

Currents

The Washington coast is subject to the complex and seasonally variable current patterns of the California Current System (description adapted from Hickey and Banas 2003). The dynamics of California Current System circulation are dominated by strong alongshore winds and the narrow continental shelf. West of the continental shelf break, a southward current (the California Current) dominates year round. The California Undercurrent flows northward over the continental slope and supplies most of the nutrient-rich water that reaches the waters over the shelf during summer upwelling conditions. In fall and winter the Davidson Current flows northward over the continental shelf and slope, along with a southward undercurrent.

A rapid change from northward-dominated winter currents to southward-dominated summer currents, known as the spring transition, signals the onset of the summer upwelling season. In fair spring and summer weather, winds accelerate surface currents southward and offshore, bringing cold, salty, nutrient-rich water to the surface and spreading fresher water from coastal estuaries away from shore and towards the south. The nutrients brought up into the photic zone (the upper portion of the water column where sunlight penetrates) nourish the planktonic base of the coastal food web. However, during storms or other periods of northward winds the currents (especially those closer to shore) are generally reversed, the system switches into downwelling, and plumes of fresh water tend to be pushed back towards the shore. Consequently, phytoplankton blooms form during upwelling events, but are pushed back towards shore during storms. In summer, local sea levels and currents are also strongly affected by coastal-trapped waves (water movements resulting from a complex interaction of shelf slope, wind, and the water's angular momentum) generated as far away as central California.

Ecologically important mesoscale (10-500 km) features such as eddies or plumes are formed by interactions between currents and coastal headlands and submarine canyons, or by intrusion of fresh water. The changes in flow patterns that occur with such features can greatly affect upwelling of nutrients, with correspondingly large effects on phytoplankton and zooplankton retention and growth rates. An eddy offshore of the Strait of Juan de Fuca, which forms in spring and dissipates in fall, shows up in satellite imagery as a consistent area of low sea surface temperature, indicating sustained upwelling. Nutrients are high in the eddy, due to wind- and topography-driven upwelling, and water from the eddy periodically moves to the Washington coast, sometimes carrying toxic algae.

The Columbia River plume also modifies coastal currents, affecting residence times and transport along the shelf, with biologically important consequences for plankton and larval fish (Simenstad et al. 1990). The plume is frequently over the Washington shelf in both summer and winter, and although terrestrial nutrients are usually depleted in the estuary in summer, mixing during upwelling provides nutrients to the photic zone (Hickey et al. 2005). At times, a strong front along the seaward side of the plume can inhibit the shoreward movement of patches of toxic algae, preventing accumulation of harmful biotoxin levels in razor clams and other harvested species. The combination of mesoscale features and coastal trapped waves on the Washington coast create mixing and upwelling and make primary productivity higher than would be expected from local wind stress values (Hickey and Banas 2008).

At a smaller scale, counter currents and eddies shape water movements that are much harder to predict and model. These smaller features, however, might prove particularly important in the case of an oil spill, determining whether or not the spill reaches vulnerable biological resources.

Tides

Tidal patterns contribute to the high biological diversity of intertidal habitats along the Washington coast. Along the outer coast, the diurnal tide range (defined as the vertical range from Mean Higher High Water to Mean Lower Low Water) varies from 7 to 8 vertical feet except in the coastal estuaries, where the range is larger (9-10.7 feet). In contrast, the inland marine waters have much larger tides, with ranges of 11.4 feet in Seattle and over 15 feet in south Sound. As a result, mid and high intertidal zones in the Puget Sound are uncovered for much longer periods of time on a daily basis, which is stressful for marine organisms. In addition, the timing of tides differs between the Sound and coast, such that the very low tides in the spring and summer occur early in the morning on the coast, when cool temperatures and frequent fog keep physical stresses low. In Puget Sound, low tides occur 4-6 hours later near midday, resulting in the exposure of intertidal organisms to greater extremes of temperature and desiccation than organisms on the coast. Tides also play a significant role in the ecological processes of Washington's coastal estuaries. In both Grays Harbor and Willapa Bay, at least half of the surface area is intertidal, with oceanic water flushing up to half of the water volume twice each day (Hickey and Banas 2003). Winter low tides at night may result in freezing conditions and widespread mortality in exposed organisms.

Climate

Climate influences ecosystem structure, function, and change at the land-air-ocean interface. Washington's extensive stretches of steep, coastal mountain ranges control the state's dominant weather systems, characterized by heavy seasonal rains and snowfall. More precipitation falls at the higher elevations and along the coast of the Olympic Penninsula, and mostly between October and March (Franklin and Dyrness 1988). Precipitation and air temperature drive seasonal changes of sea and land surface temperatures, and influence the volumes of water and sediment in river discharges, which in turn affect salinity levels in estuarine and nearshore ocean environments. High winds and waves from storms play an important role in shaping the physical environment.

From year to year, large-scale climate patterns such as the El Niño-Southern Oscillation cause system-wide differences in sea surface temperature, sea surface height anomalies, turbidity, mixed layer depth, and transport processes, with strong wave conditions during El Niño events causing major shoreline erosion along the U.S. Pacific coast (Batchelder and Powell 2002, Allan and Komar 2006, Pirhalla et al. 2009). The same physical processes also vary at an interdecadal scale, shown by the North Pacific Index (Allan and Komar 2006). These long-term patterns influence marine systems through changes in dominant species, functional dependencies, and spatial displacement, and have been recognized in the productivity of marine fisheries in the California Current ecosystem (Edwards et al. 2010; Overland et al. 2008). The frequency and intensity of climatic anomalies are being altered by anthropogenic climate change (IPCC 2007). See p. 23 for more information on climate change as a stressor on marine ecosystems.

Physical habitats and biotic communities

This section describes the major physical habitats and associated biotic communities of the intertidal, subtidal, and deep benthos and selected pelagic and terrestrial zones. Detailed information about many individual species mentioned in this section can be found in the species accounts available from the Washington Deparment of Fish and Wildlife web site.

Intertidal and subtidal benthos

The intertidal zone includes all land that is alternately submerged and exposed to air: mud and sand flats, rocky shores, and salt marshes. In most intertidal areas, there are conspicuous zones of organisms across different elevations. These zones occur because of the variation in time of exposure to air versus ocean, which affects survival and growth of marine, intertidal, and terrestrial species. The intertidal zone is covered and uncovered by tides twice a day, except the very low and very high portions which are only affected by extreme spring tides. At low tide in the intertidal zone, marine organisms must remain buried (in sand or mud) or be well adapted to changes in moisture and air exposure. Similar physical habitats and their associated communities may extend across the lower boundary of the intertidal, ranging into the subtidal benthos.

The subtidal benthos remains permanently submerged, and biological communities are often formed in the physical structure provided by key organisms (biogenic habitats). The general difficulty of mapping subtidal bottom characteristics means that less information is available than for intertidal or terrestrial zones, and the danger of bringing oceanographic boats close to shore along rough and rocky areas of the coastline means that few data are available for nearshore subtidal habitats. For much of the Washington coast, it is likely that the substrate on the nearshore bottom parallels what is seen on the shoreline, with extensive rocky areas in the north and sand in the south on the outer coast. The distribution of kelp forests along rocky shores supports this assumption, since kelp require bedrock or large cobbles in the subtidal zone to maintain a stable presence.

Estuaries

Lagoons, sloughs, bays, sounds, marshes, swamps and inlets are all examples of estuarine habitats that occur in coastal areas where fresh and saltwater mix, found where rivers meet the ocean. Estuaries are highly valuable ecosystems in cultural, economic, and biological terms. Throughout history, estuaries have been vital for Native American cultures, as evidenced by historical records as well as shell and bone deposits (middens). In addition to their cultural value, estuaries are home to more than two-thirds of Washington's commercially important fish and shellfish. Many species are lifelong residents or depend upon estuaries for a variety of life-stages including spawning and development. Estuaries are also important forage areas for visiting wildlife, such as migratory shorebirds, ducks, and geese (Cullinan 2001).

Extent

Estuarine habitat occurs along the outer coast in Grays Harbor and Willapa Bay, at the mouth of the Columbia River, and in smaller patches along the entire coast, including Conner Creek, Boone, Joe, Moclips, Quinault, Raft, Cedar, Hoh, Mosquito, Goodman, Quillayute, Ozette, Sooes and Waatch Rivers. Shorelines along Willapa Bay and Grays Harbor have such a complex, sinuous shape that if the entire coastline from Flattery Rocks to the mouth of the Columbia River were stretched out into a straight line, these estuaries would compose almost 60% of its length. The physical habitats of Washington's estuaries are categorized by substrate sediment type (sand, gravel, mud, or organics), salinity (low-salinity oligohaline to higher-salinity polyhaline), and exposure (open to enclosed; Dethier 1990). Below the salt marshes or terrestrial vegetation in the coastal areas are vast areas of mudflats. Sandflats replace the mudflats in regions that are more exposed to coastal wave energy, for example just inside the mouths of Willapa Bay and Grays Harbor. Over 80% of the shoreline in each of these estuaries is composed of sand, mud or organic material (Nearshore Habitat Program 2001).

Ecology

Marine and terrestrial forces battle for influence on estuarine processes. Compared to the Columbia River estuary, the biology of Willapa Bay and Grays Harbor is more strongly influenced by oceanic inputs due to wind-driven upwelling and downwelling events (Roegner et al. 2002); riverine inputs are low during the season when photic levels and temperatures permit the growth of photosynthetic organisms (Hickey and Banas 2003). Tides change salinity levels through variation in the extent of mixing between fresh and marine water, which breaks up the stratification of freshwater on the surface and salt water below. The degree of mixing (and consequent patterns of salinity, nutrients, and turbidity) change with the phase of the moon (Lalli and Parsons 1993). Tidal range is greatest during full and new moon phases, when the sun, earth, and moon are aligned. During these spring tides there is greater mixing between fresh and saline water. Tidal range is less during neap tides during first and third moon quarters, when stratification of fresh and saline water is greater and waters further inland have lower salinity. Different species use these different conditions during particular stages of their life-history cycle. For example, herring spawn in estuaries during neap tides, and anadromous eulachon use spring tides to reach their spawning grounds in the upper stretches of rapid rivers (Simenstad et al. 1997).

Some species are primarily found in branched channel systems that drain across the salt marshes and through the tidal flats. Channels may be unvegetated or lined with eelgrass. The substrates are used by insect larvae, amphipods, polychaetes, other invertebrates, and the numerous organisms that feed on them: predators include shorebirds, herons, raccoons, otter, mink, and fishes including salmon. This type of habitat is not quantified in the ShoreZone system.

In general, upper estuarine habitat may be dominated by a variety of plant associations, separated by elevation or often co-occurring in patches. Various grasses, forbs, and other vascular plant groups dominate. Some salt marshes are important roosting habitats for shorebirds and gulls, and haulouts for seals (Buchanan et al. 2001; Mumford et al. 2007). They are also hunting grounds for various raptor species. Elk, deer, grant, ducks, and snow geese browse in marshes, and animals living in the vegetation include a variety of voles, insects, spiders, and other invertebrates. Some estuaries feature tidal surge plain wetlands at the lower end of the river. The Chehalis River surge plain, the largest in the state, occurs just before the Chehalis River empties into Grays Harbor. The wetland is dominated by Sitka spruce (*Picea sitchensis*), with sloughs winding through areas dominated by herbs, shrubs, and wet forests. In addition to absorbing and slowing flood waters, the plain provides habitat for the Olympic mudminnow (*Novumbra hubbsi*, a State Sensitive species) and rearing and migration habitat for salmonids (Washington Department of Natural Resources 2008).

Biogenic estuarine habitat: Eelgrass beds and oyster reefs

Two important species associated with estuarine habitat, eelgrass and oysters, create three-dimensional habitat in intertidal and subtidal zones. With blades that reach up to 2 m in length, eelgrass (*Zostera marina*) forms patchy beds covering thousands of hectares in the extensive sedimentary flats of Willapa Bay and Grays Harbor estuaries (Miller 1977; Nearshore Habitat Program 2001; Borde et al. 2003; Ruesink et al. 2006). These beds provide important habitat in nearshore ecosystems (Mumford 2007), and the economic value of such habitat has been estimated at over USD 19,000 per hectare per year (Costanza 1997). Eelgrass beds provide primary production to nearshore food webs, primarily through detritus pathways as particulate organic carbon and dissolved organic matter. Brant geese (*Brant bernida*) are one of the few large animals that are direct consumers of eelgrass, and these plants are an important food source during their twice-annual migration on the Pacific flyway. Crucially, eelgrass beds provide three-dimensional structure in an otherwise flat setting, slowing water currents, dampening waves, and trapping sediments. The roots stabilize sediments in their interlocking, dense mats. Microalgae, macroalgae, and invertebrates such as copepods, amphipods, and snails -- which would not be present in flat sandy or mud areas without the structure of eelgrass beds -- are preyed on by marine-associated birds. Commercially important species such as Dungeness and red rock crab, Pacific herring, salmonids, shrimp, and flatfishes rely on eelgrass beds at some point in their life cycles (Mumford 2007).

Oysters create another three-dimensional community in the lower intertidal and subtidal zones, when oyster larvae attach to older oysters and create a densely-packed, layered habitat with a high surface area. Where oysters have declined, estuaries may be more vulnerable to eutrophication and hypoxia without the influence of oysters on water clarification, nutrient cycling, and community composition (Booth and Heck 2009). Historically, Willapa Bay and Grays Harbor supported populations of Olympia oysters (*Ostreola lurida*) in the low intertical zone and the shallow subtidal zone (Cook et al. 2000; Baker 1995). After harvest led to commercial extinction by 1930, recovery of the Olympia oyster has been hampered by removal of shell accumulations and competition, and recent aquaculture has focused on the non-native Pacific oyster (*Crassostrea gigas)* (Ruesink et al. 2005; Trimble et al. 2009).

Eelgrass and bivalves may interact with each other in a complex manner. Bivalve aquaculture planting densities and harvest methods have been shown to influence seagrass and associated benthic communities in complex ways, facilitating or depressing eelgrass growth and densities (Booth and Heck

2009; Tallis et al. 2009). At certain densities, both oysters and mussels have been shown to cause high growth rates in eelgrass by increasing the availability of nutrients, and eelgrass has been shown to increase the survival of mussels (Peterson and Heck 2001; Booth and Heck 2009). However, high oyster densities have been associated with lower eelgrass growth rates, shoot densities, and plant biomass (Simenstad and Fresh 1995).

Sand Beaches

Sand beaches are the second most common shore type in coastal Washington, comprising far more linear extent than any other besides estuarine types, especially in southern Washington. They vary in width (some beaches along the southern coast are over 300 meters wide at low tide), slope (from broad and flat to narrow and steep) and coarseness (from very fine, sometimes mixed with mud, to coarse and mixed with gravel).

Extent

The ShoreZone system lists 4 classes of shoreline with sand as the primary component: sand and gravel beach, sand and gravel flat, sand beach, and sand flat; “beaches” are defined as generally less than 30m wide and with a slope of 5-20 degrees, whereas “flats” are more than 30m wide and have slopes less than 5 degrees. Beaches are often described as being reflective of wave energy and are coarser in grain size (and therefore more likely to contain gravel), while flats are finer-grained and dissipate wave energy by causing waves to break further offshore and dissipate energy there. Other important physical differences are that finer-grained flats may hold water and organic matter whereas coarser-grained beaches are very permeable and tend to have low organic content. On the Washington coast, the four types of sand beaches together make up only 12% of the linear shoreline of the two large estuaries, but over 45% of the shoreline of the outer coast. On the outer coast, sandy beaches are found largely in the southern half of the state and tend to be broad, fine-grained sand flats.

Ecology

Due to the unstable and high-energy nature of sand beaches, they have no permanent vegetation. The finer-grained, dissipative beaches in central and southern Washington often have extensive phytoplankton blooms near shore in the surfzone (Lewin et al. 1989; Schoch 1999). This primary productivity, as well as the tendency of these beaches to retain some organic matter, means that the finer-grained beaches have more species living in them than the coarser, more reflective beaches further to the north (Dethier 1991). A number of beach-adapted species provide key food sources for other organisms, especially for shorebirds. Characteristic sand occupants include amphipods, isopods, polychaete worms, and patches of razor clams in the low intertidal and shallow subtidal zones, and mole crabs can be found in the southernmost beaches and further north in El Niño years (Dethier 1991). Fish species that use these habitats include juvenile tomcod and sole, surfperch, and staghorn sculpins. Surfsmelt spawn on the high shore in slightly more protected areas, and juvenile sandlance and candlefish feed there as larvae. Crangonid and mysid shrimp are often in the shallow waters and contribute to local food webs. At low tide, gulls, sanderling, other sandpipers, and herons use the beaches, consuming amphipods and worms, and at high tide loons, scoters, and grebes feed over them. Raccoons and crows may dig for the larger worms that are very abundant in some areas.

Related terrestrial habitat: Sand dunes

Terrestrial habitats in close proximity to the shoreline may experience strong effects from the marine environment, including salt spray and blowing sand. The southern coast of Washington, with its high-energy sand beaches, also supports sand dune habitat. Dunes are derived from sand carried by longshore drift and wind erosion, and are chronically poor in nutrients and organic matter. Patches of dunes occur from the Copalis River south to the Columbia River. Washington dunes tend to be smaller than the extensive dune systems in Oregon, rising only 4-6 m high. Sand dunes historically also occurred along the lower Columbia River.

Vegetated dunes are colonized by native or introduced grasses and various small shrubs and trees; other dunes are too unstable, due to natural or anthropogenic disturbance, to support vegetation. The lower edge of dunes is often stabilized by drift logs washed high on the beach during storms. Dunes and adjacent fine sand beaches provide important roosting and foraging habitat for shorebirds, such as sanderlings, and nesting habitat for snowy plover. Drift logs are used as feeding perches and resting places for eagles and falcons, and as windbreaks for roosting shorebirds. Dune shrubs provide habitat for overwintering passerine birds, and larger trees are used as perch sites. Various small mammals, reptiles, and amphibians find cover among the vegetation and logs.

The last active dune on the lower Columbia River is located on Sand Island in Baker Bay (Christy and Putera 1993). All other island and mainland dunes have been stabilized by vegetation (Christy and Putera 1993). The stability and future of Washington's sand dunes and sand beaches are currently the subject of intensive study due to concerns about erosion events. Many of Washington's coastal dunes have been stabilized by the introduction of two non-native beachgrass species (*Amophila*) that were intentionally introduced for this purpose. For more information, see the Southwest Washington Coastal Erosion Study website: http://www.ecy.wa.gov/programs/sea/swces/index.htm.

Mixed substrates

Complex habitats containing a mix of bedrock and soft sediments are among the hardest to clearly categorize and are biologically among the richest of coastal habitats. On the outer coast, these often comprise bedrock benches or platforms where loose substrates, ranging from large boulders to muddy sand, cover the bench across much of the intertidal zone. The underlying bedrock may hold water, such that large, shallow, and biologically rich pools form when the tide is out. These areas are often somewhat protected from wave action by coastal islands, seastacks, or kelp beds, such that incoming waves lose much of their energy before reaching the intertidal zone. The high shore is commonly a steep beach of sand or gravel.

Extent

Mixed substrates comprise the third most common habitat type, after estuary wetlands and sand beaches (Table 1). Dethier (1990) refers to these habitats as "mixed-coarse", whereas ShoreZone calls them "rock with gravel beach" or "rock with sand beach." These habitats are not found in estuaries, but comprise roughly 12% of the linear shoreline along the outer coast, predominantly in the northern half within the Olympic National Park. The biota of these habitats discussed in Dethier (1991) as "cobble areas".

Ecology

Mixed-substrate habitats are extremely rich, in part because they contain four disparate components: the surfaces of stable cobbles and boulders (which are like surfaces of rocky shores), the undersides of these rocks (which are shaded and protected), the soft-sediment substrate between the rocks (which contains various burrowing animals), and the extensive pools (which are similar to subtidal habitat). Hardshell clams can be found in areas with deeper sediment. At six sites of this type within the Olympic National Park, Dethier (1991) found 105 plant and algal species and 229 animal species. Many of these algal and invertebrate organisms were not found elsewhere along the shoreline. Mixed substrates feature high primary productivity, with high algal and surfgrass abundance, especially in the pools and on the stable boulders. Large birds and mammals visit to forage.

Rocky shores

As sand beaches dominate the coast of southern Washington, rocky shores typify the north coast. Waves hit these steep rocks with great force and send salt spray high onto the shore. The constant water motion experienced by these habitats brings food, larvae, spores, and nutrients to the species that brave the high wave action, making this an extremely productive and species-rich habitat (Leigh et al. 1987). Wind-driven coastal upwelling keeps the nearshore waters cold and rich in nutrients for much of the year. Sea stacks and nearshore rocks and kelp beds provide partial wave protection in many areas, creating patches of calmer habitat behind them. On the central Washington coast, where the rocky shores give way to increasingly long stretches of sandy beach, the rock cliffs and platforms are sand-scoured, creating a habitat occupied by a unique subset of sand-loving rocky-shore organisms. Tidepools contain both intertidal and subtidal species, and provide a favorite habitat for people exploring the shoreline. Surge channels are often unusually rich but have been less explored. The communities on the abundant nearshore islets and seastacks are also poorly studied. They probably contain most of the same species, serving as refuges for organisms susceptible to collecting or disturbance by humans. Headlands receive direct wave energy and are often associated with offshore water movement due to local upwelling, and both of these physical processes may affect recruitment of organisms and consequent community structure (Ebert and Russell 1988; Connolly and Roughgarden 1998). Tribal subsistence and ceremonial harvest is important in many areas along the rocky shores of the northern coast.

Extent

On the outer coast proper, rock cliffs, ramps and platforms together cover about 60 km of shoreline, or 15% of the linear outer coast (Table 1). Most of the rocky shores (almost 80%) are rugged cliffs (with slopes higher than 20°), 16% are ramps (5-20° slopes), and the remaining 5% are relatively flat platforms.

Ecology

From over 40 years of research on rocky-shore ecology on the Olympic Peninsula, most notably on Tatoosh Island, by researchers from the University of Washington (R.T. Paine and students), these habitats have been unusually well studied. The most conspicuous organisms inhabiting rocky shores in the region include a variety of kelps and other algae or surfgrass in the low-intertidal zone, a rich invertebrate fauna dominated by mussels, barnacles, and anemones in the mid-intertidal zone, and smaller algae and barnacles in the high-intertidal zone. Key organisms include not only the spatial dominants, named above, but their consumers: sea urchins and chitons in the low zone, seastars (especially the “keystone predator” *Pisaster*) and dogwhelks in the middle zone, and various smaller herbivores in the high zone. Large brown algae attach to intertidal substrates, forming a band the shore that is visible from the air (Nearshore Habitat Program 2001). The kelp provides food for invertebrates and a three-dimensional “understory” habitat (see below). In addition, drift kelp from this productive habitat contributes to nearshore food webs.

Much of the research on Washington’s rocky shores took place in the absence of sea otters, but since sea otter reintroduction on the Olympic Peninsula in 1969-70 the abundance of sea urchins and other critical species has been changing (Laidre et al. 2006). Strong trophic effects of sea otters on kelp, mediated by sea urchin populations, have long been recognized elsewhere (Estes and Palmisano 1974; Estes et al. 2004), but the trophic effects of the spread of this predator in Washington have not been quantified. Some organisms in this habitat are harvested for recreational and subsistence purposes (urchins, mussels, chitons, gooseneck barnacles, and various algae). Others may be few in number but are ecologically critical (such as *Pisaster*), and others are relatively rare (such as the sea palm *Postelsia*, which is on Washington State’s list of rare algae and is only found in the most wave-exposed rocky shores of the outer coast).

A diverse array of wildlife species forage on rocky shores, from otters, mink, weasels, raccoon, and deer to oystercatchers, eagles, crows, gulls, turnstones, sandpipers, and other shorebirds. Some of these birds (especially the oystercatchers, crows, and gulls) are known to have significant impacts on the ecology of rocky shores (see Marsh 1986; Wootton 1997). Cliffs and soils above the reach of the waves are used as nesting sites by colonies of seabirds, and by peregrine falcons and belted kingfishers. Harbor seals may use platforms as pupping sites, and fur seals use rocky habitats as temporary haul-out sites. Areas offshore are used by cormorants, scoters, harlequin ducks, and pigeon guillemot as foraging sites. At high tide, various fishes probably forage on rocky shores, although there has been little exploration of this topic on rugged coasts.

The biota of rocky shores are known to vary highly from year to year due to variation in recruitment, physical conditions (such as El Niño events or freezes; Dethier 1991), and other unknown causes. The physical substrate is not subject to vagaries of sediment supply in the manner of sand beaches, nor to changes in salinity in the manner of estuaries. Because organisms in this changeable habitat tend to have broad physiological tolerances, long-term changes such as climatic shifts or sea level changes may happen slowly enough that the biota of rocky shores can compensate, either by shifting their vertical distribution or by acclimating.

Biogenic rocky subtidal habitat: Kelp forests

Two species of kelp in Washington (bull kelp, *Nereocystis luetkeana*, and giant kelp, *Macrocystis integrifolia*) grow to the surface from the subtidal benthos, forming canopies visible from the shore or the air. The annual bullkelp grows at depths between the extreme low tide line and 10-30 m, whereas the perennial giant kelp prefers shallower depths from the low intertidal to 4 m (Mumford 2007). The ShoreZone database lists floating kelp as absent, patchy, or continuous along each segment of shoreline. On the outer coast, this survey recorded 55 km of linear shoreline with patchy or continuous kelp.

According to analysis of aerial photographs from 1989-2004, kelp canopy increased on the northern outer coast and in the western Strait of Juan de Fuca, with higher variance in bull kelp than giant kelp canopy cover (Berry et al. 2005).

Kelp forests are a key habitat from both a local and an ecosystem perspective. Locally, kelps increase the vertical complexity of habitat structure by expanding above the rocky bottom. This complex structural component serves as a nursery and foraging area for a variety of fishes, especially rockfishes, sculpins, greenling, lingcod, perch, juvenile salmon, and others, including many fish on Washington's list of Species of Concern. Herring spawn on kelps, invertebrates such as octopi and snails use these large algae as habitat, and sea urchins feed on them. Some smaller algae live preferentially under the canopy provided by the forest-forming kelp species. Kelp beds are the preferred habitat of the northern abalone (*Haliotis kamtschatkana*), a Species of Concern in the state. Floating kelp provides a surface habitat where wind waves are dampened, and this semi-protected surface is used as foraging habitat by scoters, loons, grebes, goldeneyes, buffleheads, and harbor seals. Sea otters feed primarily in kelp-dominated habitat, and preferentially rest in nearshore areas among floating kelp beds (Laidre et al. 2009). Sea otter distributions and sea urchin harvest may influence kelp abundance (Berry et al. 2005; Laidre et al. 2006). Large kelp beds are also thought to physically affect adjacent shoreline communities by damping wave energy and thereby providing some protection for otherwise-exposed coastlines (Eckman et al. 1989). Kelp beds have been shown to indirectly affect nearby intertidal communities by harboring the predators of the larvae of intertidal invertebrates (Gaines and Roughgarden 1987).

Kelp forests and other macroalgae also play a key role in producing detritus (Duggins and Eckman 1994). Approximately 500 species of green, brown, and red algae have been documented on the coast (Waaland 1997). Sections or entire plants break loose during storms and wash up on beaches, where they are scavenged by small crustaceans, insects, and other scavengers. Decomposing kelp supplies dissolved organic matter and particulate organic matter to the nearshore waters (Mumford 2007). Erosion of growing kelp leaves also supplies particulate and dissolved organic matter to the water column, fueling bacterial growth which supplies zooplankton and benthic filter-feeders. Kelp-derived carbon outstrips the contribution of phytoplankton in nearshore food webs where it is present (Duggins et al. 1989).

Deep benthos

Although deep corals were reported on the Pacific coast as early as the 1860s, and were noted from National Marine Fisheries Service bottom trawl surveys since the 1970s, the extensive survey work needed to document their populations has only taken place since the 1960s (Whitmire and Clarke 2007). Following a pilot survey in 2004, National Oceanographic and Atmospheric Administration scientists led a spring 2006 research trip using a remotely operated vehicle to document coral and sponge communities at mean depths between 89-313 m (Brancato et al. 2007). The same ship, the *McArthur II,* made another research trip in summer 2010 using both remotely controlled and manned submersibles. Work funded by Washington Sea Grant between 2007 and 2009 found glass sponge reefs on the Washington continental margin. The researchers also accidentally discovered a large field of methane vents that may harbor methane-eating bacteria which provide a year-round boost to the productivity of the marine food web (P. Johnson, University of Washington, personal communication).

Biogenic deep benthic habitat: Corals and glass sponges

Extent

In the Olympic Coast National Marine Sanctuary, 48 sites have been identified that have hard substrates in the right depth range to support coral habitat. Of these sites, remotely operated vehicles have been used at 15 sites for photographic transects, and corals and sponges were documented at 14 of them (Brancato et al. 2007). However, the mapping work needed to identify potential habitat covers only about ¼ of the sanctuary, so many areas occupied by corals likely remain to be found.

Ecology

Coral and sponge species found in the Olympic Coast National Marine Sanctuary include gorgonians (sea whips and fans), stony corals such as *Lophelia pertusa* and *Desmophyllum dianthus*, and the reef-building sponge *Farrea occa* (Brancato et al. 2007). Bamboo (family Isididae) and bubblegum (family Paragorgiidae) corals occur just outside the sanctuary (Etnoyer and Morgan 2003). Much of the habitat in the sanctuary is formed by boulder fields or single, house-sized boulders.

The three-dimensional structure of corals and sponges provides important habitat for fish and invertebrates. The 2006 sanctuary survey documented 18 species of corals, more than 40 species of sponges, and more than 30 species of fish, including 10 species of rockfish, thornyhead, sole, halibut, skate, lingcod, and sablefish (Brancato et al. 2007). The survey also found shark egg sacks, crab, shrip, and many echinoderms associated with corals and sponges, and observed multiple species of echinoderms feeding on them.

Nearshore pelagic

The nearshore (neritic) pelagic zone is conventionally defined as the water column over the continental shelf up to 200 m depth (Lalli and Parsons 1993).

The planktonic food web

Planktonic organisms, both unicellular and multicellular, do not have the swimming power to direct their own movements over large scales (as opposed to nekton, the true swimmers). Phytoplankton and bacteria form the base of the pelagic food web, supporting zooplankton, small pelagic fish, and top predators including fish, seabirds, marine mammals, and humans (Miller 2004). The pelagic food web is an important source of production for coastal ecosystems, along with nearshore detrital and benthic sources.

Extent

Growth of phytoplankton is usually controlled by the availability of either nutrients or light, and their growing populations are eventually controlled by predators such as zooplankton and small pelagic fish (Miller 2004). The photosynthetic pigment *chlorophyll a* contained in phytoplankton can be measured by satellites from space, such that the productivity of marine waters can be indexed at a global scale. High productivity commonly occurs at fronts (sharp transitions in water properties) where mixing or upwelling bring limiting nutrients into the photic zone (Lalli and Parsons 1993).

Ecology

For decades, marine ecologists have treated nearshore planktonic habitats as a "black box" – difficult to sample, but suspected of being important to processes along coastlines. Improved sampling methods, including moored larval collectors that also gather physical data, have shown that the combination of nearshore upwelling, currents, and winds, along with the abundances of larvae of benthic organisms in the plankton, can indeed influence the supply of larvae that colonize the shore. Populations of benthic organisms can be limited by the supply of larvae, and this issue is very important in terms of recolonization of disturbed areas (for example, after an oil spill) and of transport and connectedness among marine protected areas (see Dethier et al. 2003; Shanks et al. 2003).

The tiny phytoplankton and zooplankton support the food chains that include benthic herbivores, benthic carnivores, zooplanktivorous fish, piscivorous fish, seabirds, marine mammals (including planktivorous whales, which boast the largest organisms ever known on the planet), and one terrestrial mammal whose technology allows it to hunt at sea: *Homo sapiens* (Lalli and Parsons 1993).

Biogenic pelagic habitat: Floating algal mats

Kelps, and to a lesser extent other algae or seagrass, are occasionally torn loose from the substrate but do not wash ashore; rather, they get entrained in longshore currents or are washed out to sea. Unanchored kelps (such as bullkelp) with healthy reproductive structures have been found hundreds of kilometers outside their range (K.A. Miller and D.O. Duggins, personal communication). This rafting may serve to colonize areas where populations have been destroyed by disturbances. Algal mats may provide an important dispersal mechanism both for the algae themselves (since most large algae have propagules that only travel meters or perhaps kilometers in the plankton) and for the small invertebrates that are often associated with these mats (see Helmuth et al. 1994; Ingólfsson 1998; Dethier et al. 2003). This drifting habitat is present year-round, and provides physical structure in otherwise open water (Buckley and LeClair 1999). Some species of rockfish spend their larval and juvenile stages associated with drifting algal mats, feeding on abundant epiphytic and planktonic organisms associated with algal mats and growing quickly (Kingsford 1992, 1995; Shaffer et al. 1995).

Anthropogenic stressors

Human activities have the potential to enhance or degrade the habitats and species of the Washington coast. Quantifying these effects is often difficult, because environmental forces and human activities interact in ways that are only partially understood. Small variations in oceanographic conditions, which are also only partially understood and not intensively monitored, can cause large differences in species and ecosystems. The impact of a given human activity on species and ecosystems can vary dramatically as environmental conditions change in response to both short-term and long-term environmental cycles (Palumbi et al. 2008). Individual anthropogenic impacts do not occur in isolation from each other (Figure 3); Halpern et al. (2009) found that every area on the Pacific coast from Washington to Baja California was affected by at least five of the human impacts they analyzed. The complexity inherent in marine systems, in combination with multiple, interacting anthropogenic stressors and ever-increasing, highly valued uses of marine areas, support the growing call for more integrated, ecosystem-based management of the coast (Washington State Ocean Policy Work Group 2006; Levin and Lubchenko 2008; Ruckelshaus et al. 2008; West Coast Governors' Agreement on Ocean

Health 2008; Lester et al. 2010; Puget Sound Partnership 2010; Tallis et al. 2010). In the following sections, we review the habitat-specific effects of anthropogenic stressors of particular relevance to Washington's coastal ecosystems.

The outer coast lacks a comprehensive system to monitor the status of habitats or ecosystems, but the Olympic Coast National Marine Sanctuary issued a Condition Report in 2008 that examined the pressures on sanctuary resources, assessed the current status of those resources, and listed the management responses to each pressure (Office of National Marine Sanctuaries 2008). Information from their report is included in this section.

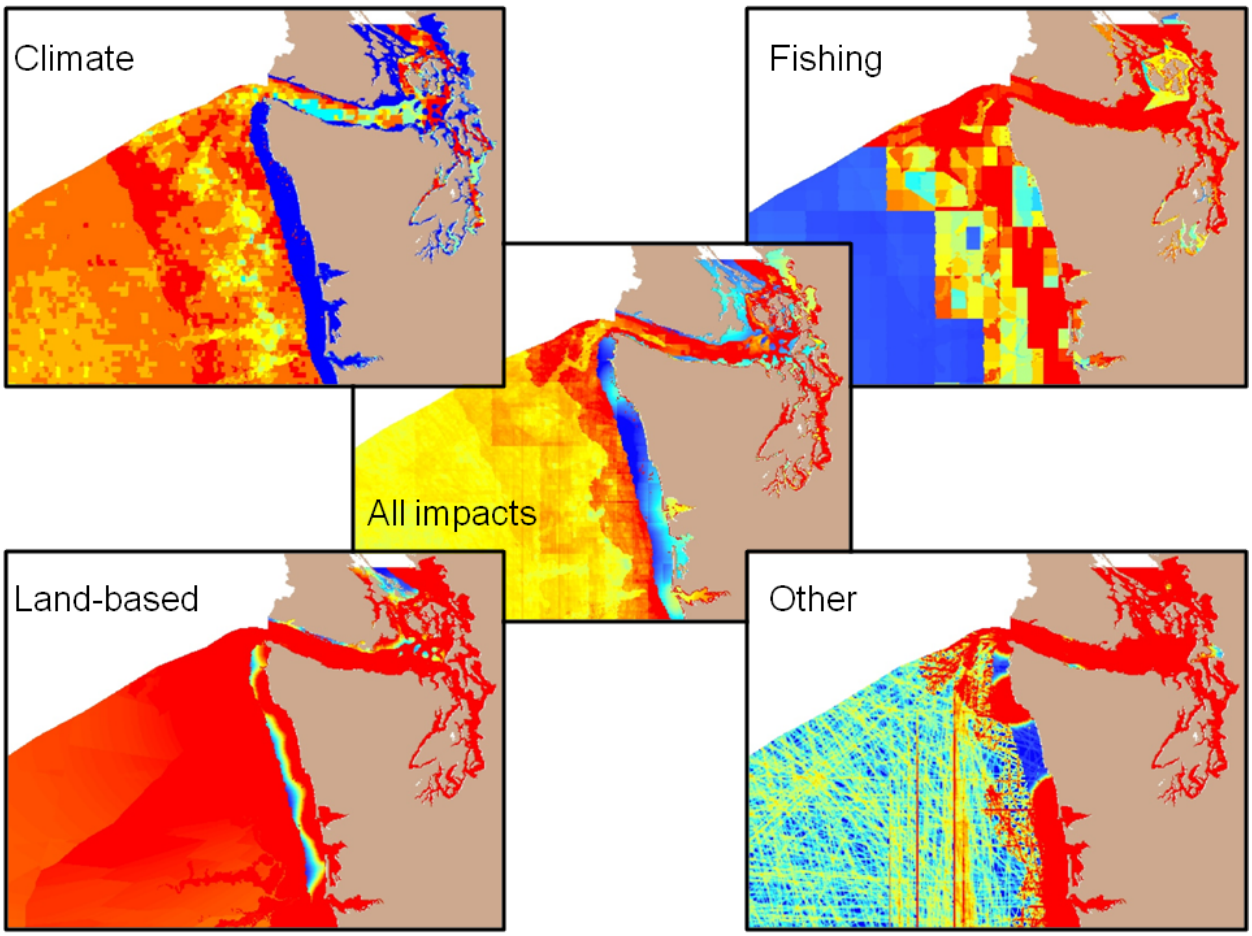


FIGURE 3: CUMULATIVE IMPACT MAPS OF HUMAN ACTIVITIES IN WASHINGTON'S MARINE WATERS. COLORS ARE SCALED TO DATA SHOWN, WITH WARM COLORS FOR HIGHER IMPACT AND COOL COLORS FOR LOWER IMPACT. DATA AND IMAGES ARE FROM B. HALPERN, NCEAS/UCSB, PER METHODS DESCRIBED IN HALPERN ET AL. 2009. THE CATEGORY "OTHER" INCLUDES COMMERCIAL SHIPPING, INVASIVE SPECIES, OCEAN-BASED POLLUTION, MARINE DEBRIS, AND AQUACULTURE.

Oil pollution

The most visible impacts of catastrophic oil spills on the Washington coast are oiled shores and wildlife, such as the 13,000 oiled seabirds found after the *Nestucca* spill (Ford et al. 1993; U.S. Fish and Wildlife Service 2004). However, actual mortality is estimated to be several times greater than the number of carcasses recovered. The *Tenyo Maru* spill in 1991 killed thousands of common murres (*Uria aalge*) and 7-11 % of the total outer coast population of the federally threatened marbled murrelets (*Brachyramphus marmoratus*), and is suspected to have damaged the giant kelp beds in the area of Tatoosh Island (Momot 1995; *Tenyo Maru* Oil Spill Natural Resource Trustees 2000; *Tenyo Maru* Trustees 1993).

The risk of an oil spill in Washington's coastal waters persists. In 2006, 5.7 billion liters of oil were transported through the Strait of Juan de Fuca, totaled across transits by 1,400 oil tankers and 5,500 freighters (Office of National Marine Sanctuaries 2008). Although portions of the Olympic Coast National Marine Sanctuary have been designated as an "Area to be Avoided" by such traffic (Office of National Marine Sanctuaries 2008) and a response tug has been stationed at Neah Bay, a catastrophic spill remains a possibility and its impacts on coastal ecology would depend on spill, wind, and sea conditions at the time.

Research needs

In the event of a spill, some oil evaporates, leaving the more dense, viscous, and carcinogenic portions behind (Strickland and Chasan 1989). If the spilled oil floats on the surface, its movement will be primarily affected by winds. For portions of the oil that are physically mixed or chemically dispersed in the water column, movements will be governed principaly by near-surface currents (Strickland and Chasan 1989) including the Columbia River plume (Landry et al. 1989). A working group of the Olympic Coast National Marine Sanctuary has identified a priority need to explore under what ocean conditions the use of dispersants might be effective.

Since the Exxon Valdez spill released 42 million liters of crude oil into Prince William Sound and nearby shores in Alaska, environmental toxicologists have expanded their research beyond short-term, acute toxic effects to investigate long-term biological impacts and ecological recovery (reviewed by Peterson et al. 2003). In Prince William Sound, oil has persisted for decades in intertidal sediments (especially in coarse-grained gravel beaches and stream banks and under mussel beds) where it is not rapidly degraded. This residual oil can chronically expose sediment-affiliated species such as fish, sea otters, and seaducks (Peterson et al. 2003; Short et al. 2007; Li and Boufadel 2010). Although these long-term exposure levels are sublethal, various species and populations have experienced compromised long-term health, growth, and reproduction (Peterson et al. 2003). Following the Exxon Valdez spill, indirect effects of the spill were demonstrated to have spread through the ecosystem via trophic relationships (trophic cascades), loss of key individuals in socially organized species (Matkin et al. 2008), or changes to biogenic habitat such as marine algae or grasses (Peterson et al. 2003). Such long-term, sublethal effects of oil -- and the chemical dispersants used in oil spill response -- are receiving increased attention (see Culbertson et al. 2008; Gonzalez et al. 2009), and the 2010 Macondo (Deepwater Horizon) blowout in the Gulf of Mexico has catalyzed additional research (Kerr et al. 2010). Current Natural Resource Damage Assessment procedures for scaling impact and planning restoration for oil spill events in Washington underestimate these sublethal and ecosystem-level effects (D. Doty, Washington Department of Fish and Wildlife, personal communication). In Washington State, the Makah Tribal Council and the Northwest Indian Fisheries Commission have expressed concern about the possible impacts of dispersant use to the Makah Usual and Accustomed Marine Area (FR 2009 Vol 74, No. 167).

Estuaries

The acute effects of spilled oil in the habitat types found on the Washington coast are well documented, and some of the most severe and long-lasting damage can occur when oil spills contaminate estuarine habitats. As occurred from the *Nestucca* spill, oil could enter Washington's coastal estuaries if driven by onshore winds, especially if transported by tidal currents. Oil could cover vegetation and animals and become incorporated into sandy and muddy sediments. Because estuaries have relatively low wave energy, oil on the substrate or in sediments will not degrade quickly. Oil that becomes incorporated into muddy sediments may persist for decades, because the degradation of oil by natural or introduced bacteria requires oxygen and this substrate typically is anaerobic within 1 cm below the surface (Teal et al. 1992). Consequently, in the National Oceanic and Atmospheric Administration's Environmental Sensitivity Index (Table 2) used to classify the vulnerability of shoreline habitats to oil impacts, sheltered tidal flats and marshes rank 9 and 10, respectively, with 10 being the most vulnerable (National Oceanic and Atmospheric Administration 2008).

Oil can directly kill and injure animals found in estuaries (Strickland and Chasan 1989). Seabirds and shorebirds with oiled feathers and marine mammals such as sea otters (*Enhydra lutris*) and river otters (*Lontra canadensis*) with oiled pelage may die from toxic effects of ingested oil ingested when preening, or from hypothermia from loss of waterproofing and thermal insulation. Despite human efforts at cleaning those animals that can be captured, long-term survival is highly variable and reproductive capacity may be adversely affected, with effects depending greatly on the oil type, the season, the experience and skill of the rehabilitators, and the species (Anderson et al. 1996; Massey et al. 2005). Fish such as juvenile salmon using estuarine habitats may also be poisoned by contaminated water or prey, and significant oil contamination would likely close one or more commercial shellfish harvest seasons.

TABLE 2: ENVIRONMENTAL SENSITIVITY INDEX OF SALT SHORELINE HABITATS (ADAPTED FROM NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION 2008).

Ranking	Habitats
1	Exposed rocky shores
2	Exposed platforms or steep slopes in bedrock, mud, or clay
3	Fine to medium-grained beaches
4	Coarse-grained sand beaches
5	Mixed sand and gravel beaches
6	Gravel beaches
7	Exposed tidal flats
8	Sheltered rocky shores
9	Sheltered tidal flats
10	Marshes and wetlands

Beaches

Specialists previously believed that long-term effects of oil on sand and gravel beaches would be less severe than for estuaries. The small crustaceans, worms, and bivalves that live in these beaches (providing food for shorebirds and other species) are very vulnerable to spilled oil (Conan 1982, Wolfe et al. 1996), but these habitats were thought to be amenable to shoreline cleanup techniques. Also, it was believed that the high wave energy that maintains these habitats would disperse and break down trapped oil. However, these assumptions are not universally applicable, as demonstrated by recent work showing that oil in the subsurface layers of some of Prince William Sound's gravel beaches has persisted 20 years after the Exxon Valdez spill (Li and Boufadel 2010).

Mixed substrates

For mixed-substrate habitats, oil spills also can cause persistent impacts. Oil could readily be deposited on the cobble-sediment platforms, killing species in pools and on the rocks and becoming incorporated into the sediment. Oil that reaches one of these broad platforms may get carried to the high beach component and deposited on sand, gravel, and logs, as occurred during the *Nestucca* spill. Where offshore formations and surface substrate provide protection from wave energy, oil in subsurface sediment layers can persist for years and continue to expose organisms to oil. Like sand and gravel beaches, mixed-substrate subsurface sediments were still saturated by oil decades after the spill at some sites after the Exxon Valdez oil spill (Peterson et al. 2003; Li and Boufadel 2010).

Rocky shores

Scientists contend that rocky shores are less vulnerable than other shoreline habitats to the effects of oil spills, because oil is not entrained in sediment and wave action can clean them relatively quickly, but this assumption was also challenged following the Exxon Valdez and other spills (Peterson et al. 2003). Both toxic effects of oil and direct mechanical effects of cleaning procedures to remove oil can kill marine organisms (Peterson et al. 2003). Oil, cleaning agents, or dispersants also can have sublethal effects on growth and reproduction. Following the Exxon Valdez oil spill, oil was retained within mussel beds, weathering only slowly continually exposing mussels, which are key prey for other species ranging from fishes and seastars to sea otters and bears (Peterson et al. 2003). Following the complete destruction of rocky intertidal communities by Exxon Valdez oil spill and mechanical cleanup activities, several species showed atypical, unstable population cycles during recovery from spill impacts, presumably because of the loss of normal mixed-age populations and trophic interactions (Paine et al. 1996, Peterson et al. 2003).

Oil spills are particularly damaging to kelp habitat. The attachment point and microscopic phases of kelp are on the bottom of the water column and thus vulnerable to oil that reaches the seafloor through natural processes or chemical dispersion. The majority of the biomass of floating kelps (*Macrosystis*) and reproductive structures (*Nereocystis*) are near the water surface and thus vulnerable to oil that remains near the water survace, as are kelp-associated organisms ranging from juvenile rockfish to sea otters. Kelp blades have been known to trap oil floating on the ocean's surface, making it easier for cleanup crews to collect oil but increasing exposure and causing irreversible damage to the plants themselves (Antrim et al. 1995). Kelp forests provide protected habitat for numerous juvenile and adult fish and their prey. Consequently, these organisms can be directly (exposure to oil) or indirectly (loss of habitat) impacted by oil spills.

Nearshore pelagic

In the nearshore pelagic zone, oil spills directly harm birds and marine mammals that encounter surface slicks, either by destroying the insulating characteristics of their feathers or fur, or from toxic effects from ingestion when trying to clean the oil from their bodies (U.S. Fish and Wildlife 2005). Floating algal mats, which are an important refuge for juveniles of some species of rockfish, tend to concentrate oil (Buckley and LeClair 1999). Oil, dispersants, and dispersed oil have the potential to affect the entire water column and the organisms such as juvenile fish found there, but research is needed to quantify such effects.

Climate change

We do not yet fully understand how climate changes may affect ocean circulation and upwelling intensity, but effects on primary productivity, hypoxia, and trophic ecology are likely to be significant and specific to organisms and habitats (Bakun 1990; Bakun and Weeks 2004; Bakun et al. 2010). In a recent regional assessment of 25 impacts of human activities on the California Current coast, Halpern and colleagues concluded that climate change is the top threat, due to ocean acidification, increased UV levels, and high sea surface temperatures (Halpern et al. 2009). Measuring the oceanographic and ecological effects of anthropogenic climate change against the background variability, especially multi-decadal oscillations such as the Pacific Decadal Oscillation, is very challenging (Edwards et al. 2010). Further research will be needed to untangle the effects of climate change from other anthropogenic stressors, such as fisheries bycatch and direct harvest (Rolland et al. 2008; Wilson 1991), a task made more complex by the different time scales over which different organisms will react to stressors (Overland et al. 2008). The Washington Climate Change Impacts Assessment (Climate Impacts Group 2009) developed scenarios to assess the impacts of climate change on multiple sectors in the Pacific Northwest, including the coasts, energy, hydrology and water resources, and salmon.

Estuaries

The entire character of coastal estuaries is likely to be affected by climate change through alteration of annual precipitation, sea level, winds, and currents. Sea level rise and changes in seasonal runoff are anticipated to cause, in some places, coastal inundation, flooding, and erosion, as well as saltwater intrusion in freshwater aquifers (Huppert et al. 2009). Climate change has been associated with increasing wave heights and stronger storms, which along with higher mean water levels may cause increased or severe erosion along the entire west coast of the U.S. (Allan and Komar 2006). More acidic oceans will likely harm wild shellfish as well as the shellfish aquaculture industry (Thom et al. 2001). Water temperature and carbon dioxide concentration changes may alter benthic nutrient cycling (Thom et al. 2001), increase stress to aquatic organisms, cause shifts in distributions, and affect eelgrass and kelp growth rates and densities (R.M. Thom, personal communication). For example, eelgrass density varied five-fold during a transition from El Niño to La Niña conditions (Thom et al. 2003).

Deep benthos

Climate change will likely affect deep coral communities through altered ocean chemistry, specifically through the carbonate concentrations at various depths. Different coral species form their skeletons from aragonite or calcite, and those that use aragonite (scleractinians such as the structure-forming *Lophelia pertusa* and most stylasterids) are likely to be most affected by these changes (Whitmire and Clarke 2007).

Nearshore pelagic

Climate change has been associated with changes in the upper trophic levels in marine ecosystems; the sooty shearwater, a numerically dominant species in summer in the California Current System, declined 90% between 1987 and 1994, concurrent with an increase in sea surface temperature and not explained by other causes (Veit et al. 1997; Lyver et al. 1999). Warm sea surface temperatures resulted in drastically decreased growth rates and fledgling success of tufted puffin (*Fratercula cirrhata*) nestlings (Gjerdrum et al. 2003). Climate change likely interacts with other human impacts (such as bycatch in fishing gear, or direct harvest) to affect species dynamics (Rolland et al. 2008; Wilson 1991). Many fish species are likely to respond to changing climate with range and depth shifts, changing their trophic relationships and complicating human efforts to manage fisheries (Perry et al. 2005).

Harvest and human disturbance

Intensive harvest of a target species can obviously impact population dynamics of the target species, but harvest and other human activities may also indirectly affect non-target species.

Estuaries

Harvest of estuarine species may have profound ecosystem effects. For example, eutrophication in the Chesapeake Bay over the last 70 years is suspected to have been worsened by the overharvest of oysters, which had previously filtered phytoplankton blooms from the water column (Jackson et al. 2001). In Washington, the deliberate introduction of the non-native Pacific oyster, *Crassostrea gigas*, has resulted in the accidental introduction of predatory non-native oyster drills and the use of pesticide to control populations of burrowing shrimp in some areas (especially widespread in Grahs Harbor) because they are damaging to juvenile oysters (Feldman et al. 2000). Washington’s only native oyster, the Olympia oyster, was harvested to commercial extincton, has been lost from much of its range, and is now a State Candidate species subject to reintroduction throughout the state (Trimble et al. 2009). The processes involved in shellfish aquaculture (such as harrowing, dredging, raking, or leveling the substrate, as well as increasing the density of cultured animals) may alter the sediment structure and dymanics, change nutrient levels, and cause shifts in community composition. For a review of these effects, see Simenstad and Fresh (1995) and Dumbauld et al. (2009).

Beaches

On sand beaches, humans walking and beach-combing are largely non-destructive, although beach walking can result directly or indirectly in the flushing of wildlife, nest destruction, and bird mortalities, especially if the walker is accompanied by an unleashed dog or aerial predators are present (Flemming et al. 1988; Lafferty 2001). Driving or horseback riding on the shore is allowed with seasonal restrictions on hard sand portions of beaches landward of razor clam beds and outside of the Olympic National Park. This type of disturbance primarily affects the physical habitats and the species that use them for nesting and foraging. Human uses of dunes and beaches are managed during nesting seasons to prevent disturbance of the snowy plover and streaked horned lark (Pearson et al 2008).

Harvesting of razor clams occurs at several sandy beaches along the outer coast and is managed by the Washington Department of Fish and Wildlife, coastal treaty tribes, and the National Park Service. To maintain a sustainable harvest, these agencies estimate population sizes and determine allowable harvest levels. Tribal fisheries manage a commercial harvest for razor clams. The Department then sets regionally appropriate “bag limits” and harvest openings to stay within those harvest levels. They also control harvest levels and impacts associated with harvest by setting gear requirements and by regulating beach use. In general, razor clam beaches regularly experience high physical energy and are tolerant of harvest disturbance.

Mixed substrates

Humans tend to use mixed-substrate habitats lightly, since these habitats have fewer edible species and are physically difficult to traverse. However, some mixed-substrate sites have substantial numbers of clams which are harvested by tribal and non-tribal recreational users.

Rocky shores

Human disturbance and harvest of a variety of organisms impact rocky shores in coastal Washington. Tribal harvest targets a wide variety of species, both algal and invertebrate; non-tribal use targets fewer species, mostly mussels and gooseneck barnacles (Dethier and Deering 1996, Dethier et al. 1989). Collection of mussels and gooseneck barnacles often is accomplished by scraping patches of organisms from rock, leaving an open patch which may or may not be recolonizedby the same species and which leaves adjacent organisms vulnerable to physical forces. While the National Park Service and Washington Department of Fish and Wildlife regulate non-tribal harvest, effective enforcement is limited along the full length of the coastline. Additionally, an increasing body of literature reports on the adverse effects of human foot traffic on rocky shores, even when no organisms are being collected. Trampling can have locally significant, direct negative effects on both algae and invertebrates, particularly at locations where visitation is focused. Human use of the shoreline also scares away birds and mammals that feed and rest there. Live organisms collected for souvenirs, such as sea stars or other organisms in shells, usually do not survive the experience. Research has documented such impacts elsewhere (see Beauchamp and Gowing 1982; Brosnan and Crumrine 1994; Jenkins et al. 2002) and on a localized basis in Olympic National Park (Erickson 2005), but the extent of this activity on the outer coast is not well studied.

Proposals for direct human harvest of kelp beds in Washington have been periodically put forward and rejected (T.M. Mumford, Washington Department of Natural Resources, personal communication), but this remains a potential future activity. Human harvest of urchins and sea cucumbers from kelp beds is regulated by the Washington Department of Fish and Wildlife, but the impacts of this harvest on kelp beds have not been investigated in Washington State. No urchin or sea cucumber harvest currently takes place on the Washington coast.

Deep benthos

Efforts to map seafloor habitats and identify locations of habitats most critical to ecosystem function are proceeding slowly, which limits management responses in the absence of such data. However, the limited surveys completed to date show that fishing gear can damage deep coral and sponge communities through direct contact (Whitmire and Clarke 2007) or through damage from lost gear

(Brancato et al. 2007). A remotely operated vehicle survey in the Olympic Coast National Marine Sanctuary in 2006 documented dead coral associated with lost fishing gear and other anthropogenic debris (Brancato et al. 2007). Bottom trawling by non-tribal fishers is prohibited by the National Marine Fisheries Service in some vulnerable areas (the 'Essential Fish Habitat' areas, which make up about 15% of the total area of the Olymplic Coast National Marine Sanctuary) to prevent damage from gear (Brancato et al. 2007). State waters are also closed to bottom trawling to protect seafloor habitats.

Outside of Washington, oil and gas exploration and exploitation causes disturbances (physical damage or destruction, sedimentation) to deep coral and sponge communities, but such development is not allowed in the portion of the coast covered by the Olympic Coast National Marine Sanctuary (Whitmire and Clarke 2007). The deployment of communication cables may cause localized damage to corals and sponges, but the extent of the threat and duration of the impact has not been fully explored (Whitmire and Clarke 2007). There is no direct harvest of corals on the Washington coast (Whitmire and Clarke 2007).

Nearshore pelagic

Humans affect Columbia River discharge patterns by controlling flow through multiple dams on the river. The plume of low-salinity water from the outflow of the river influences the dispersal patterns of many intertidal, subtidal, and pelagic marine species (Hickey et al. 2005). The discharge is responsible for 77% of the total freshwater drainage into the Pacific Ocean between San Francisco and the Strait of Juan de Fuca (Budinger et al. 1964). The plume varies naturally among years with the El Niño Southern Oscillation and on shorter time scales with smaller meteorological events, so effects on marine organisms of anthropogenic changes to discharges are difficult disentangle from natural or other anthropogenic changes (Thom and Borde 1998).

Seabirds and marine mammals can be inadvertently injured or killed by certain types of fishing gear; may face competition for the same prey species that are targeted by fisheries; or may be affected by ecosystem structural changes resulting from fishing activities (summarized by Mills et al. 2005; U.S. Fish and Wildlife Service 2005). Documenting demographic effects of fisheries interactions on specific seabird colonies is difficult and requires monitoring the movements of individual birds to detect overlap between seabird foraging and fishing activities (for an example, see Hamel et al. 2008). According to the California Current Marine Bird Conservation Plan (Mills et al. 2005), only a few fisheries in the United States result in significant seabird bycatch. Of these 17 fisheries along the U.S. Pacific coast, 8 have at-sea observer programs to document bycatch rates and estimate mortality rates (Mills et al. 2005). The West Coast Groundfish Observer Program (implemented by the National Marine Fisheries Service, Northwest Fisheries Science Center) records wildlife bycatch for all groundfish fleets. In fisheries in state and federal waters off the Washington outer coast, the two fisheries with observer programs have documented seabird bycatch (recreational fishing vessels and groundfish trawls). The Pacific Fishery Management Council banned pelagic longline gear, for which seabird bycatch has been documented, in federal waters in 2002. This gear is also banned in Washington State waters, so it is only used outside of the 200-nautical mile limit of U.S. jurisdiction.

Washington Sea Grant is successfully working with coastal Treaty tribes and the non-tribal commercial longline fleets to reduce albatross and fisheries interactions by providing streamer lines free of charge (which scare birds away from baited hooks before they sink below the birds' range), protecting the birds and preventing bait loss by seabirds (E. Melvin, University of Washington, personal communication). This technique has been extremely successful at reducing interaction rates in Alaska, Canada and other parts of the world. Other techniques to increase fishing efficiency, such as scheduling fishing activities for peak target species abundance, or deploying visual or acoustic alerts to deter seabirds, provide benefits to both seabirds and fishers (Melvin et al. 1999).

Fisheries may also have ecosystem impacts through direct harvest. Small pelagic fish, like anchovy, herring, and eulachon, form a crucial link between the trophic levels above and below them that can be disrupted by overfishing (Bakun 2006). In Washington State waters, Washington Department of Fish and Wildlife precautionary management policy takes into account the wide fluctuations in abundance that occur in such fish populations, and considers the role of the fish in the ecosystem when developing management plans (Fish and Wildlife Commission 1998). Krill harvest was banned along the U.S. Pacific coast by the National Marine Fisheries Service in 2009.

The Northwest Training Range Complex comprises multiple areas used for training by the U.S. Navy, including areas on the outer coast of Washington (Department of the Navy 2010). Military training operations may disturb wildlife at sea or on shore, as well as human commercial and cultural activities associated with natural resources. Chief concerns include mid-frequency or high-frequency sonar and underwater detonations (National Oceanic and Atmospheric Administration 2010).

Non-native, invasive species

Non-native and invasive species can cause displacement of native species through predation, competition, or changes in habitat structure, and they can alter local trophic dynamics, degrade habitats, and reduce local productivity (National Research Council 1996).

Estuaries

The non-native, invasive Atlantic cordgrass (*Spartina alterniflora*) poses a significant threat to Washington's coastal estuaries by colonizing unvegetated mudflats and saltmarsh communities. Since its accidental introduction at the end of the 19^{th} century, and deliberate use to stabilize shorelines, *Spartina* spread to infest over 9,000 acres of tidelands statewide in 2003 (Washington State Department of Agriculture 2007). This invasion causes significant ecosystem changes. Once *Spartina* is established on unvegetated mudflats, sediment accretes around the plant clones, raising the substrate over time and converting a mid- or low-shore mudflat to a high-shore marsh intersected by deep channels (Washington State Department of Agriculture 2007). The loss of mudflats results in the loss of a significant ecosystem and its resoures. For example, mudflats in Washington are annually used by millions of migrating shorebirds for foraging, and mudflats provide habitat for native and cultured oysters. In addition, *Spartina* out-competes native marsh vegetation and alters the invertebrate infauna and epifauna (summarized in Elston 1997; Cordell et al. 1998; O'Connell 2002). The state and federal governments (coordinated by the Washington Department of Agriculture) have had tremendous success controlling *Spartina* in Willapa Bay by using multiple techniques including mowing, mechanical crushing, and herbicides, reducing the coverage of *Spartina* to less than 100 acres in 2010 (Washington Department of Agriculture 2010). In Grays Harbor and the Columbia River estuary the areas of infestation are much smaller, but if left uncontrolled would clearly threaten important mudflat habitats.

The introduced Japanese eelgrass (*Zostera japonica*) generally occurs in previously unvegetated areas at higher intertidal elevations than the native eelgrass (*Zostera marina*), but does not appear to be an important competitor and may in fact facilitate *Z. marina* at a landscape scale (Ruesink et al. 2009).

Other intertidal and subtidal habitats

Two other non-native and invasive species of great concern are the European green crab (*Carcinus maenas)*, also know as the European shore crab) and the Chinese mitten crab (*Eriocheir sinensis*; Elston 1997; Cohen et al. 2001). In Washington, European green crabs have not been observed on rocky shores or cobble beaches but are associated with tidal and salt marshes and oyster beds in Willapa Bay and Grays Harbor. The green crab is a predator on commercial shellfish and has the potential to compete with the native Dungeness crab (McDonald et al. 2001). After the first official report of a live green crab in Washington State in 1998, an emergency regulation prohibited transfer of shellfish from Willapa Bay to other state waters without a permit. That same year, the crab was listed as a deleterious species, making it illegal to possess a live green crab without a Washington Department of Fish and Wildlife Scientific Permit. Rapid response and initiation of a trapping program in 1998 has kept the populations in check in Willapa Bay and Grays Harbor (Washington Department of Fish and Wildlife 2010). Monitoring in the Olympic Coast National Marine Sanctuary near Neah Bay has not detected the species. In contrast, the distribution of the mitten crab in Washington is not well understood. A single male mitten crab was found in the Columbia River in 1997 and other sightings have been reported since. This species is not believed to be well established or to currently pose a risk to native species or commercial shellfisheries.

Invasive species currently appear to be less of a threat on exposed rocky shores and in mixed-substrate habitats. The cultured mussel *Mytilus galloprovincialis* has been found in marinas in Neah Bay and Sekiu, but not yet on the shoreline at nearby Tatoosh Island. It is ecologically very similar to the native *M. trossulus*, and there is concern about hybridization or replacement (Wonham 2001). The invasive large brown alga *Sargassum muticum* tends to be found in areas not fully exposed to wave action, but is present at some coastal sites in the shallow subtidal zone. *Sargassum* can have negative effects on the abundance and growth rates of native algal assemblages, including understory kelps (Britton-Simmons 2004), which could result in reduced numbers of juvenile fishes that prefer these kelps (K.H. Britton-Simmons and J. Hayden-Spear, personal communication). *Sargassum muticum* was also common at some mixed-substrate sites surveyed by Dethier (1991), and is a concern for managers of the Olympic Coast National Marine Sanctuary (Office of National Marine Sanctuaries 2008), but no monitoring occurs to document its distribution or impacts on native algae. Some populations of the abundant green alga *Codium fragile* may be an introduced subspecies, but ecological impacts have not been investigated.

Nearshore pelagic

Non-native, invasive species may colonize estuaries via ballast water expelled from ships; at least nine planktonic copepods have invaded Pacific coast estuaries from ballast water (Cordell et al. 2010). Ballast water discharges in state waters are regulated by the Washington Department of Fish and Wildlife.

Habitat loss

Estuaries

The coastal estuaries of Grays Harbor and Willapa Bay have not suffered the same extensive scale of development and industrial uses as found in Puget Sound, but have experienced changes due to physical alteration such as filling and diking, as well as changes in watershed and development along terrestrial margins. Salt marshes have been removed directly by shoreline development or diking for agricultural uses, and tidal flats in Willapa Bay and Grays Harbor have decreased by over 20% since the 19^{th} century (Borde et al. 2003). Development activities can increase riverine sediment loads, alter erosion regimes, and may change the timing and volume of freshwater input. Eelgrass, which provides important biogenic estuarine habitat, is particularly sensitive to such changes in water quality (Williams and Heck 2001).

Beaches

A major threat to the high-energy sand or sand-gravel beaches of Washington's coast is natural and anthropogenic change in sediment supply. Many beaches are dynamic because of wide variation in currents, winds, waves, and sediment supply. Historically, most of the sediment feeding Washington's beaches came from rivers (especially the Columbia, for the outer coast beaches) and from eroding bluffs. For the past 100 years or so, the coastal beaches have been accretionary, with shorelines building up over 5 m/year at times (Southwest Washington Coastal Erosion Study 2008). In the 1990s there was a series of 'coastal erosion crises' such as breaches of jetties and major sand-erosion events. This prompted the initiation of the Southwest Washington Coastal Erosion Study to study the effects of long-term coastal change, the effects of dams on the Columbia River, jetty construction, and natural wave and climatic conditions (Southwest Washington Coastal Erosion Study 2008; see p.40 for more information on the study).

Mixed substrates

Relatively little is known about the formation and ecology of mixed-substrate habitat types relative to others on the coast, making it difficult to assess threats. Presumably, these habitats could be threatened by long-term changes in sediment supply because one physical component of this habitat is sediment. A reduction in sediment could result in loss of the infaunal habitat component, and an increase could result in smothering of many cobble-inhabiting species.

Harmful algal blooms

Nearshore pelagic

As has occurred along many of the world's coastlines, harmful algal blooms have been more frequently document in nearshore marine waters of the U.S. in recent years, including Washington State's coastal waters (HARRNES 2005). Prior to 1991, domoic acid was not monitored on the West Coast, but there is speculation that *Pseudo-nitzschia*, a toxin-forming species, may have been introduced to the region via ballast water (Thom and Borde 1998). Since 1991, when blooms of *Pseudo-nitzschia* produced accumulations of domoic acid in razor clam tissue to cause a coast-wide closure, 22% of planned harvest days associated with this popular shellfish species have been lost to health-associated closures (D. Ayres, Washington Department of Fish and Wildlife, personal communication). This includes three season-long, coast-wide closures in 1991-92, 1997-98 and again in 2002-03, in addition to shorter closures in smaller areas (U.S. House Hearing 2003). Although the algal blooms may not pose a threat to the shellfish themselves, these lost harvest opportunities due to human health concerns resulted in the loss of millions of dollars of tourism-related income for many small communities along the Washington coast (Bauer et al. 2010; Dyson and Huppert 2010). A smaller area closure of the commercial Dungeness crab fishery also occurred in Willapa Bay in 2003 when domoic acid contaminated crab tissue (U.S. House Hearing 2003).

Echoing an event in 1993, the summer 2009 appearance of a phytoplankton species of the genus *Alexandrium* (which can cause paralytic shellfish poisoning) caused great concern to shellfish managers. While levels of *Alexandrium* did not result any widespread shellfish closures, it has persisted in the surf zone and may be a major problem in the future (D. Ayres, Washington Department of Fish and Wildlife, personal communication). Washington State, in cooperation with federal, state, university and tribal scientists, has an active coastal harmful algal bloom-monitoring program called the Olympic Region Harmful Algal Bloom (ORHAB) project (Trainer and Suddleson 2005). The recently completed Ecology and Oceanography of Harmful Algal Blooms project (ECOHAB, funded by the National Oceanic and Atmospheric Administration) has shown that domoic acid-producing blooms of *Pseudo-nitzschia* frequently initiate in the Juan de Fuca eddy off the northwest Washington coast (Trainer et al. 2009). This finding adds to the strong likelihood that harmful algal bloom events will continue to persist along the Washington coast (U.S. House Hearing 2009).

Some plankton blooms have direct impacts to coastal wildlife. In the late summer and fall of 2009 a large bloom of the dinoflagellate *Akashiwo sanguinea* produced a foam containing surfactant-like proteins, coating the feathers of multiple species of seabirds and neutralizing their natural water repellency and insulation capacity, exposing the birds to hypothermia and killing thousands along the coast in Washington and Oregon (National Centers for Coastal Ocean Science 2009). This bloom was similar to an event in late 2007 in Monterey Bay, California (Jessup et al. 2009).

II. Management of the Washington coast

Coastal ownership and management

Ownership of coastal areas in Washington is a complex issue. Aquatic lands, under water along the shore, are generally under state ownership, unless that ownership was transferred from the state. Upland ownership extends either to the high water line or a meander line (if ownership was assigned before Washington obtained statehood). The latter category may include some aquatic lands. Shorelands, submerged along a river or lake, are about 75% state owned. Tidelands, which this report calls intertidal, are alternatately exposed and submerged by tides and are about 30% state owned. Bedlands, permanently submerged under both salt and fresh water, are generally state owned. Kelp and eelgrass, being attached to the bottom of intertidal and subtidal ares, are state owned. In those areas not under other management agreements, they are managed by the Department of Natural Resources in conjunction with the Washington Department of Fish and Wildlife. Tribal co-management of natural resources is described in the sections below. A brochure from the Washington Department of Natural Resources provides further details: http://www.dnr.wa.gov/Publications/aqr_aquatic_land_boundaries.pdf.

Washington's Coastal Zone Management Program (Swanson et al. 2001) is based primarily on the Shoreline Management Act of 1971. The act requires cities and counties with shorelines (marine and certain fresh waters) to prepare Shoreline Master Programs which are reviewed by the Department of Ecology. Management of specially protected coastal areas is described in the section on marine protected areas below.

Governmental coordination

State Ocean Caucus

In 2005, the Washington State Legislature responded to a series of national reports on the need for improving ocean management and policy by directing the Governor's office to investigate state ocean resources and management. The Washington State Ocean Policy Work Group was formed to respond to this charge, and included representatives from state agencies and commissions, county commissioners, members of the State Legistlature, stakeholder groups, and city, county, and port associations, with tribal representatives serving as observers. In their 2006 report, the Ocean Policy Work Group provided recommendations for improving protection and management of Washington's ocean resources, including establishing an ongoing interagency team on ocean policy (Washington State Ocean Policy Work Group 2006).

Accordingly, the State Ocean Caucus was formed in 2007 to prioritize activities, to implement the recommendations of the Ocean Policy Work Group, improve agency coordination, and to improve ocean resource management in Washington State, with participation from state Departments of Agriculture, Commerce, Ecology, Health, Fish and Wildlife, and Natural Resources, the Military Department's Emergency Management Division, the Office of Financial Management's Executive Policy Office, Puget Sound Partnership, State Parks and Recreation Commission, and Washington Sea Grant.

The Caucus work plan includes activities related to ocean energy, education, marine debris, ocean research, climate change, coastal hazards, sediment management, sustainable communities, offshore aquaculture, ecosystem-based management, and partnerships. In response to SB 6350, the group prepared a report to the legislature in containing recommendations for marine spatial planning in Washington, including a framework for planning, goals and objectives, and management and information needs (Hennessey and State Ocean Caucus 2011). The Renewable Ocean Energy Action Coordination Team of the West Coast Governors' agreement on Ocean Health addresses marine spatial planning in adjacent federal waters.

Olympic Coast Intergovernmental Policy Council

The Olympic Coast Intergovernmental Policy Council was created through a Memorandum of Agreement adopted in January 2007 between tribal, state, and federal governments. The Council is comprised of representatives from the four coastal treaty tribes—the Makah, Quileute, and Hoh Tribes and the Quinault Indian Nation— and the State of Washington, represented by staff from the Governor's Office. The Council provides a forum for communication and exchange of information and policy recommendations regarding the management of marine resources and activities within the boundaries of the Olympic Coast National Marine Sanctuary.

Marine Resource Committees

Marine Resource Committees are county-based, volunteer committees that foster local projects and activities and advise the county and the State Ocean Caucus on issues pertaining to marine resources within a county, or several counties. Committees are composed of representatives from local and tribal governments, local citizens, economic, recreational and conservation interests, and the scientific community. Through their activities and meetings, the Committees coordinate diverse partners, support action-oriented solutions, and provide a forum for education and outreach on regional marine management issues. There are currently three Marine Resource Committees on the coast: Grays Harbor; Pacific; and North Pacific (a joint effort between Clallam and Jefferson counties). Wahkiakum County is also authorized to form a Marine Resource Committee, which is in the early stages of development.

Marine protected areas

The high value of the habitats encompassed within the Washington coast, both in terms of species, habitat, ecosystem functions, and human uses, has generated a variety of protections for certain marine areas. These designations indicate concern about the vulnerability of these habitats and their associated natural resources. Jurisdiction over intertidal and marine areas in the state is complex, with management provided by federal, state, tribal, and local agencies (Van Cleve et al. 2009). In addition to the major areas described below, the Washington Department of Natural Resources and Washington Parks and Recreation Commission manage 11 natural areas and parks with marine and/or shoreline components on the south outer coast. Siting and management of existing marine protected areas has not been coordinated, and little monitoring occurs to ensure that conservation objectives are being met (Van Cleve et al. 2009). In addition to state agencies, private individuals, aquaculture companies, and non-profit organizations such as The Nature Conservancy also conduct conservation activities that contribute to management of marine areas in Washington.

Olympic Coast National Marine Sanctuary

The Olympic Coast National Marine Sanctuary was designated in 1994, and extends along 217 km of shoreline between Koitlah Point (6 km east of Cape Flattery) and the Copalis River, reaching 40-72 km offshore (Office of National Marine Sanctuaries 2008). The primary objective of this National Marine Sanctuary is protection of an area of rich cultural and biological diversity: kelp beds, subtidal reefs, rocky and sandy intertidal areas, submarine canyons, deep-sea rocky habitat, and plankton-rich upwelling zones. Twenty-nine species of marine mammals and over 100 species of seabirds occur in the Sanctuary (Office of National Marine Sanctuaries 2008). Human communities have survived on this coast for at least 6,000 years, and the Sanctuary boundary overlaps the traditional (Usual and Accustomed) fishing areas for four coastal Indian tribes (Office of National Marine Sanctuaries 2008). The Sanctuary facilitates multiple uses consistent with conservation, including recreational and commercial harvest of razor clams and diverse marine fisheries.

Olympic National Park

The Olympic National Park owns and manages almost 120 km of wilderness coast adjacent to the terrestrial park lands, with rocky headlands, beaches, tidepools, and sea stacks. Intertidal areas along the park boundary were transferred to the park's ownership in 1986, but continued to be open to fishing and shellfish harvest in conformity with the laws and regulations of the State of Washington. Accordingly, the Washington Department of Fish and Wildlife continues to implement conservation and management activities within the park's Pacific Coastal Area, working closely with the Olympic National Park in the management of the large non-treaty recreational fishery for razor clams in the Kalaloch area. The department conducts razor clam population surveys and recreational harvest surveys, and establishes harvest seasons. Harvest of certain intertidal species (particular foodfish and shellfish defined in Washington Department of Fish and Wildlife sport fishing rules) is allowed, but no harvest of other species is allowed except under tribal rights to access marine natural resources. The par also manages intertidal portions of offshore islands within the Washington Maritime National Wildlife Refuge Complex. In addition to protecting the natural resources, the park provides recreational and educational opportunities.

National Wildlife Refuges

The U.S. Fish and Wildlife Service manages the national system of National Wildlife Refuges, which provide haven for wild plants and animals and opportunities for compatible human activities such as wildlife observation, photography, hunting, fishing, and education. Of the nine Refuges with a marine component in Washington State, five are found on the outer coast. Flattery Rocks, Quillayute Needles, and Copalis National Wildlife Refuges contain 870 coastal rocks and reefs, stretching over 160 km of coastline from Flattery Rocks to Copalis Beach. These three refuges form the Washington Maritime National Wildlife Refuge Complex. The islands provide nesting habitat for more than 150,000 seabirds (of 14 species), resting areas for hundreds of thousands of migrating birds, foraging and rafting areas for sea otters, and haulout sites for sea lions and harbor seals. The islands are closed to public access (without a Special Use Permit), but wildlife observation from land or from boats at least 200 yards away is encouraged.

Grays Harbor National Wildlife Refuge, in the Grays Harbor Estuary at the mouth of the Chehalis River, is a major staging area for up to one million migrating shorebirds (up to 24 species) in the Pacific Flyway. An accessible boardwalk facilitates education and interpretation activites.

Willapa National Wildlife Refuge (established in 1937 by President Franklin Roosevelt) preserves salt marshes, tideflats, beaches, marhes, and dunes, which provide habitat for salmon, eelgrass, shellfish, and breeding or migrating waterfowl and seabirds. During migration, over 100,000 shorebirds may concentrate there. Management includes eradicating invasive *Spartina* grass to preserve tideland habitat. The Chinook, Chehalis, and Kwalhioqua peoples have lived and hunted in these coastal areas for over 2,000 years, and continue spiritual and cultural events. Access by the public is limited based on seasonal use by wildlife at these two estuarine refuges.

Species and habitat monitoring and management

Birds

The Washington Department of Fish and Wildlife's Wildlife Science Division, in cooperation with the U.S. Fish and Wildlife Service, conducts annual coast-wide marbled murrelet (*Brachyramphus marmoratus*) at-sea monitoring (see Raphael et al. 2007; Pearson et al. 2010; and Huff et al. 2006) and Snowy Plover monitoring (see Pearson et al. 2009). While conducting murrelet surveys, observations of other species are recorded and ten-year trends for all species adequately covered by this program are currently being analyzed and will be published in the near future.

The Catalog of Washington Seabird Colonies (Speich and Wahl 1989) was produced by U.S. Fish and Wildlife Service and identifies the location of coastal seabird colonies, the species using each colony and their estimated abundance. The catalog will be updated in 2011 as a database by the Washington Department of Fish and Wildlife and the U.S. Fish and Wildlife Service. The Olympic Coast National Marine Sanctuary also conducts seabird surveys to document the pelagic distribution and abundance of resident and non-resident seabird species.

State and federal agencies conduct annual monitoring of waterfowl and other migratory bird populations as part of the Midwinter Waterfowl Survey in January (Collins and Trost 2010). Data are available from 1955-2010 for Grays Harbor and Pacific counties. Canada goose subspecies composition and harvest data are also collected by cooperative state and federal monitoring programs.

Tribal waterfowl hunting

Treaty tribes set hunting regulations for their members, and cooperate with the Washington Department of Fish and Wildlife on setting regulations and rebuilding and augmenting game populations. Tribal hunters do not require a state license. Federal, tribal, and state regulators cooperate via the Pacific Flyway Council.

State waterfowl hunting

The Washington Department of Fish and Wildlife has management authority for all non-tribal waterfowl hunting within the state (http://wdfw.wa.gov/hunting/). All non-tribal small game hunting, including for waterfowl, requires a small game license, and hunting migratory birds, including ducks, geese, coots, snipe, band-tailed pigeons, and mourning doves requires an additional state migratory bird hunting validation. For ducks and geese, a federal migratory bird stamp is also required. Species-specific reporting is required to hunt sea ducks and brant. Hunting is managed by regulations restricting seasons, daily bag limits, possession limits, season limits, hunting hours, and area restrictions. Firearms, decoys, and shot types are restricted by state and federal regulations. State regulatory activity includes citizen input via the Washington Waterfowl Advisory Group and cooperation with federal agencies, other state agencies, and tribes via the Pacific Flyway Council. Washington Department of Fish and Wildlife conducts annual surveys of coastal waterfowl populations.

Invertebrates and fish

Current fish species monitoring programs primarily reflect species of commercial and recreational harvest value. Other taxonomic groups such as zooplankton or non-fished benthic invertebrates, which are strongly affected by anthropogenic stressors in the nearshore environment, are not currently monitored.

Tribal fisheries

In accordance with treaties dating to the 1850s, Indian tribes retained fishing and hunting rights in their Usual and Accustomed areas. As affirmed by federal court decisions in the 1970s and 80s, the tribes and state have co-management responsibilities for salmon, steelhead, groundfish, and shellfish resources. Co-management of most salmon stocks is conducted through the Pacific Fishery Management Council (see below) and the North of Falcon process, with state and tribal experts sitting on technical and policy bodies to set seasons for tribal and non-tribal fishers in coastal waters. Co-management of crab and razor clams are accomplished through state/tribal fishery management plans that are negotiated annually between the state and individual tribes. The tribes are supported in science-based management by the Northwest Indian Fishery Commission (http://www.nwifc.org). Of the 17 tribes with usual and accustomed areas in marine waters, the Hoh, Quileute, and Makah Tribes and the Quinault Indian Nation hold usual and accustomed treaty fishing areas on the outer coast. Tribes promulgate regulations governing harvest by tribal members, who do not require a Washington State fishing license. Finfish and shellfish harvest are managed with species-specific reporting requirements and restrictions on fishing hours, gear restrictions including gillnet mesh size, bag limits, catch quotas, and area closures.

State waters

The Washington Department of Fish and Wildlife has management authority for all non-tribal fisheries occurring within state waters (all waters within state and from the shore to three miles offshore along the outer coast) as well as fisheries occurring in federal waters that are not managed by a federal fishery management plan or for which the state has been delegated authority.

Sportfishing (recreational, non-commercial harvest) of marine fish, shellfish, and seaweed requires a license and must follow regulations established for the purposes of conservation by the Washington Department of Fish and Wildlife (http://wdfw.wa.gov/fishing/regulations/). Regulations may specify species-specific reporting requirements, catch quotas, gear restrictions, possession limits, size limits, or area closures. Harvest of shellfish (clams, oysters, and mussels) is also restricted by the Washington Department of Health in accordance with health concerns. Species not listed under Washington

Department of Fish and Wildlife definitions as food or game fish or shellfish (unclassified species) may not be harvested.

State-managed non-tribal commercial fisheries in Pacific Ocean waters include Dungeness crab, pink shrimp, spot prawns, and hagfish. The Washington Department of Fish and Wildlife adopts regulations for the anchovy and sardine fisheries and conforming regulations for federally managed fisheries. Management includes species-specific reporting requirements and regulation of size limits, release, and gear type and use, including mesh size and how long a net may remain in the water.

Federal waters: International Pacific Halibut Commission

Pacific halibut are managed by the International Pacific Halibut Commission, which is comprised of three commissioners each from the United States and Canada. Pacific halibut range from Alaska and along the West Coast to northern California. The commission conducts an annual setline survey and a coastwide stock assessment. Commission staff develops recommendations for annual quotas (total allowable catches) for each of the different halibut management areas. The West Coast (which includes Puget Sound and coastal waters off Washington, Oregon, and northern California) is included in one management area (Area 2A). The commission takes into account the advice from two advisory bodies: a Conference Board comprised of tribal, commercial, and recreational harvesters; and a Processor Advisory Group. They also take into account advice from other entities, such as the North Pacific and Pacific Fishery Management Councils and the National Marine Fisheries Service. The commission adopts annual catch and fishing regulations for each of the management areas, and the allocation or catch sharing of those annual quotas is decided through other management forums.

For the West Coast, the Pacific Fishery Management Council has developed a Pacific Halibut Catch Sharing Plan that describes the specific amounts allocated to the tribes and commercial and recreational fisheries. Commercial fisheries include a directed halibut fishery and incidental catch allowances in the groundfish longline fishery north of Point Chehalis, Washington, and the salmon troll fishery coastwide. The quota for the recreational fishery is further divided amongst regulatory catch areas within each state. Washington has four recreational subareas—Puget Sound (inner Sound and Strait of Juan de Fuca), north coast (areas around Neah Bay and La Push), south coast (area around Westport), and Columbia River (extends south of Leadbetter Point, Washington, to Cape Falcon, Oregon), which is a shared management area with Oregon.

Federal waters: Pacific Fishery Management Council

As one of eight regional councils created by the Magnuson-Stevens Fishery Conservation and Management Act, the Pacific Fishery Management Council is responsible for managing fisheries within the Exclusive Economic Zone, which extends from three miles (the state management boundary) to 200 miles offshore, through the use of Fishery Management Plans. Recommendations for fishery management actions are made by the Council to the Secretary of Commerce and the National Marine Fisheries Service. The Pacific Council is comprised of 14 voting members and includes representatives from the National Marine Fisheries Service, the treaty tribes, the state fishery management agencies of California, Oregon, Washington, and Idaho, and additional non-governmental representatives from those states. The Pacific Fishery Management Council has adopted plans for salmon, groundfish, coastal pelagic species (sardine and anchovy), and highly migratory species (albacore tuna). The salmon management plan addresses chinook and coho salmon, as well as pink salmon in odd-numbered years, but it does not include sockeye, chum salmon, or steelhead. The groundfish management plan is extremely complex, covering over 90 species and including several conservation measures to protect and rebuild overfished rockfish stocks and protect essential fish habitat. The Pacific Council recently approved an individual quota program for the West Coast groundfish trawl fishery, which will provide additional conservation restrictions, such as 100% observer coverage and individual accountability for catch and bycatch. In addition to these management plans, the Pacific Council is in the process of developing an Ecosystem Fisheries Management Plan (for 2012) which will be a framework to take into account potential ecosystem impacts resulting from management actions and could include additional measures to protect prey species.

Marine mammals

All marine mammals are protected under the Marine Mammal Protection Act, which prohibits take (actions that harass, hunt, capture, or kill animals, or attempt to do so) without a permit or exception. Some marine mammal species are also protected under the Endangered Species Act. Both laws are enforced by the National Oceanographic and Atmospheric Administration's Office of Law Enforcement and the Washington Department of Fish and Wildlife Enforcement Program. Since the early 1980s, the Northwest Region Marine Mammal Stranding Network, managed by the National Oceanographic and Atmospheric Administration, has collected information on strandings in Oregon and Washington. Volunteers at academic institutions, state and federal agencies, and other institutions provide data and respond to stranding events.

The Atlas of Seal and Sea Lion Haulout Sites in Washington (Jeffries et al. 2000), a cooperative effort by the Washington Department of Fish and Wildlife, the National Oceanographic and Atmospheric Administration, and the Cascadia Research Collective, identifies the haulout locations, habitats used, and abundance for harbor seals, elephant seals, California sea lions, and Steller sea lions. The atlas will be updated in 2011. Surveys to determine trends in pinniped (seal and sea lion) abundance have been conducted and analyzed as allowed by funding (see Jeffries et al. 2003; Pitcher et al. 2007). The Washington Department of Fish and Wildlife and U.S. Fish and Wildlife Service conduct annual or semi-annual sea otter surveys (see Laidre et al. 2002; Jameson and Jeffries 2007, 2008, 2010).

Tribal whaling

The Makah Tribe retains whaling rights under the Treaty of Neah Bay of 1855. Traditional harvest of gray whales (*Eschrichtius robustus*) was suspended in the 1920s because commercial whaling severely reduced their population, but was revived after the species recovered and was removed from the Endangered Species List in 1994 (http://www.makah.com). One whale was harvested in 1999, but additional harvest requires a permit from the International Whaling Commission and a waiver of the U.S. Marine Mammal Protection Act moratorium from the U.S. Secretary of Commerce, which the Makah tribe has requested.

Washington Department of Fish and Wildlife's Priority Habitats and Species Program

Washington Department of Fish and Wildlife's Priority Habitats and Species program identifies priorities for management and conservation. The program maps the locations of priority species and habitats and provides information on the conditions required to maintain healthy populations. Priority species require protective measures for their perpetuation due to their population status, sensitivity to habitat alteration, and/or recreational, commercial, or tribal importance. They include Washinton State Endangered, Threatened, Sensitive, and Candidate species; animal aggregations considered vulnerable; and those species of recreational, commercial, or tribal importance. Priority habitats are those habitat types or elements with unique or significant value to a diverse assemblage of species. A Priority habitat may consist of a unique vegetation type or dominant plant species, a described successional stage, or a specific structural element.

The Priority Habitats and Species program has identified and mapped a number of priority species along the coast of Washington including some molluscs, arthropods, echinoderms, marine mammals, birds and fish and their associated habitats. A list of priority habitats and species may be found on the Priority Habitats and Species web site (http://wdfw.wa.gov/conservation/phs/).

Environmental monitoring

National Aquatic Resource Surveys

Through 2006, physical and biological information were gathered at coastal sites by the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program. The coastal component of this program was a partnership between EPA, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and coastal states. Surveys using statistically-based survey design and ecological indicators began in small and large estuaries in 1999 and 2000, respectively; intertidal areas in 2002; and on the continental shelf in 2003 (Partridge 2007; Wilson and Partridge 2007). In Washington, the survey covered 71 randomly-selected sites in Puget Sound, 61 sites in intertidal areas, and 50 offshore sites. Ecological indicators include general habitat condition (dissolved oxygen concentration, depth, salinity, temperature, pH, sediment characteristics, water column characteristics such as chlorophyll-a, dissolved nutrients, and total suspended solids, and vegetation); pollution exposure condition (sediment and fish-tissue contaminants, sediment toxicity, and marine debris); and biotic condition (diversity and abundance of benthic fauna and bottom-dwelling fish, fish abnormalities, and invertebrates living on the sediment surface). Ongoing survey work is part of the National Aquatic Resource Surveys conducted by EPA, states, and tribes (http://water.epa.gov/type/watersheds/monitoring/nationalsurveys.cfm).

Northwest Association of Networked Ocean Observing Systems

The Northwest Association of Networked Ocean Observing Systems (NANOOS, http://www.nanoos.org/) is a regional partnership among state, tribal, and local government entities, industry, academic institutions, and non-governmental organizations formed in 2003 to integrate and expand regional marine observation, data management, analysis, and outreach capacity across Washington, Oregon, and northern California. NANOOS is part of the national Integrated Ocean Observing System, led by the National Oceanographic and Atmospheric Administration, which integrates regional systems across the country. NANOOS focuses on research to enhance maritime operations, increase understanding of ecosystem stressors like hypoxia and harmful algal blooms, provide data needed for regional fisheries, and assist in understanding climate change and mitigation of coastal hazards. The system includes buoys, radar, and beach and shoreline observation programs.The Pacific Coast Ocean Observing System forms the federal complement to NANOOS, focusing on federal waters.

Environmental Assessment Program

The Washington Department of Ecology's Environmental Assessment Program runs several programs that monitor environmental conditions on the Washington coast. The Marine Water Quality Monitoring program monitors stations in Grays Harbor and Willapa Bay as part of NANOOS. The Beach Environmental Assessment, Communication and Health Program is run in collaboration with the Washington State Department of Health and monitors bacteria levels at popular, high-risk beaches and communicates problems to users.

Ocean Observatories Initiative

The Ocean Observatories Initiative, a program of the National Science Foundation Division of Ocean Sciences, funds and manages the construction of a network of instruments, undersea cables, and instrumented moorings spanning the Western Hemisphere. The program is managed through the Consortium for Ocean Leadership (http://www.oceanleadership.org/). The University of Washington is leading the design, development, and construction of the Regional Scale Nodes component of the Initiative, running 800 km of high-power and high-bandwidth cable across the sea floor spanning the Juan de Fuca tectonic plate. Instruments and moorings will provide data in real-time. Other components include a northern loop of the cabled observatory from the west coast of Vancouver Island and other cables and moorings along the Pacific coast.

Coastal Observation and Seabird Survey Team

The Coastal Observation and Seabird Survey Team (http://depts.washington.edu/coasst) works through a network of citizen-scientists to monitor the occurrence of dead birds on marine shores, which provides insight into local marine resources and ecosystem health. Volunteers receive training to identify beached birds, and pledge to survey a particular beach monthly. The data provide a baseline to assess impacts of weather, climate change, ecosystem productivity, fisheries bycatch, and pollution on coastal seabird populations, including assessing damage from oil spills, chronic pollution, or entanglement.

Intertidal Monitoring

To monitor natural variability and trends in intertidal communities on a very fine, site-level scale, Dethier (1991) began a program to regularly monitor the outer coast. This monitoring has been continued by Olympic National Park and expanded to help to identify the long-term effects of recreation and climate change on coastal habitats. While a long-term database has been generated by this work, results have not yet been extensively analyzed. More recently, additional intertidal monitoring has been implemented by the Partnersrhip for Interdisciplinary Studies of Coastal Oceans (http://www.piscoweb.org) under the Coastal Biodiversity Survey between Alaska and Baja California and by the Multi-Agency Rocky Intertidal Network at rocky intertidal areas between California and Washington.

Canopy-forming kelp has been monitored yearly since 1989 by areal photography during late summer at low tide (Berry et al. 2005; see p.15 for more information on abundance). Kelp and eelgrass were surveyed and mapped by the Department of Natural Resources in the late 1990s and published in the ShoreZone data set (Berry et al. 2001). While eelgrass is monitored by the Washington State

Department of Natural Resources Nearshore Habitat Program in Puget Sound, the outer coast is not covered.

Fish and Shellfish Safety Monitoring

The Washington State Department of Health monitors biotoxin levels and closes harvest areas when levels pose a threat to human health. The program also classifies shellfish growing areas as approved, conditionally approved, restricted, or prohibited, based on a shoreline survey, marine water sampling, and pollution transport potential. Pollution and biotoxin levels are communicated through the Department of Health's website (http://www.doh.wa.gov). The department also studies contaminant levels in fish and isues consumption advisories for commercial and recreational fish harvests in the state when contaminant levels pose a danger to human health.

Southwest Washington Coastal Erosion Study

The Southwest Washington Coastal Erosion Study is a cooperative research project between the U.S. Geological Survey and the Washington Department of Ecology's Coastal Monitoring and Analysis Program. Its research has led to an improved understanding of how the movement of sediment has changed over time. Jetty construction, dredging and sand management, wave conditions, sediment budgets, and the influence of El Niño events on the movement of sand are all factors that play a role in shaping the morphology and dynamics of sandy beaches. The program continues applied research on the Columbia River littoral cell, between Tillamook Head, Oregon and Point Grenville, Washington to inform land use planning and resource management to protect beach habitat.

Oil spill response

Northwest Area Contingency Plan

If an oil spill or hazardous substance threatens Washington, Oregon, and Idaho, the Northwest Area Contingency Plan guides the response to the incident (Northwest Area Committee 2010). The plan, required by federal statute, describes how lead federal and state agencies coordinate response actions with the responsible party and tribal and local governments, using an Incident Command System. The Northwest Area Contingency Plan includes 27 regional Geographic Response Plans, which identify sensitive natural and cultural resources by geographic region. The Washington Department of Ecology administers the 12 Geographic Response Plans that address marine and estuarine waters of Washington State including the Lower Columbia River. The plans are intended to guide initial response actions in the first 48 hours or until a Unified Command is operating (or the spill is cleaned up), and thus serve as "first response" orders for the spill response. The plans describe shoreline types and sensitive fish and wildlife resources, and prioritize responses (such as strategies for "booming") designed to minimize oiling impacts to protect natural and cultural resources in the case of an oil spill.

The Northwest Wildlife Response Plan (Chapter 9970 *in* Northwest Area Committee 2010) details how the Wildlife Branch of the Incident Command System protects, identifies, rescues, processes, and rehabilitates oiled or threatened wildlife during an oil spill response. The Wildlife Branch works to provide care for affected wildlife and to minimize losses by preventing injury to wildlife from both the oil and from the spill response. Trained observers are deployed to determine the extent of initial wildlife impacts, and estimate anticipated damage. Specific responses are detailed for birds, sea otters, and orcas. Response actions are subject to requirements of the Migratory Bird Treaty Act, the Endangered

Species Act, and the Marine Mammal Protection Act, and guidelines for handling of oiled or threatened wildlife are incorporated in the Wildlife Response Plan. Indian Tribes retain sovereign authority for wildlife management responses within reservation boundaries. Washington is also a party to a Memorandum of Cooperation among the U.S. Pacific coastal states and the Canadian province of British Columbia to ensure effective coordination in the event of a transborder spill. The Canada-United States Joint Marine Pollution Contingency Plan enables cooperation at the national level.

Ecological restoration

The National Oceanographic and Atmospheric Adminstration's Damage Assessment, Remediation, and Restoration Program (http://www.darrp.noaa.gov/) and the Department of Interior's U.S. Fish and Wildlife Service (http://www.fws.gov/contaminants/issues/restoration.cfm) serve as trustees for coastal natural resources, collaborating with other federal, state, and tribal entities in the case of an oil spill. They work with local organizations, the public, and those responsible for the incident to remediate and restore the injured habitat, and to monitor the success of restoration projects.

As co-trustees for coastal natural resources, the U.S. Fish and Wildlife National Wildlife Refuge System, the Washington Department of Natural Resources, and the Washington Department of Fish and Wildlife conduct restoration activities on managed lands and other affected areas. As discussed above in the "Invasive, non-native species" section beginning on p. 27, *Spartina* eradication is a significant example of ecological restoration in outer coast estuaries.

Restoration activities following an oil spill depend on the legal settlements reached by the resposible parties and the trustees of the natural resources harmed. The settlements may not involve the specific resources damaged in the spill, but may instead call for research, monitoring, and restoration of particular species and habitats (Momot 1995; *Tenyo Maru* Oil Spill Natural Resource Trustees 2000; U.S. Fish and Wildlife Service 2004).

III. Research priorities for the Washington coast

Research needs

Recent years have brought increasing attention to the oceans and coasts, from national efforts such as the Pew Oceans Commission (2003) and the U.S. Commission on Ocean Policy (2004) to a regional call to action by the governors of California, Oregon, and Washington (West Coast Governors' Agreement on Ocean Health 2008) and the 2008 Pacific Coast Collaborative Agreement among Alaska, British Columbia, California, Oregon, and Washington (http://www.pacificcoastcollaborative.org).

Prior to the establishment of the Olympic Coast National Marine Sanctuary, coastal research planning took place under the federal Regional Marine Research Program, overseen by the National Oceanographic and Atmospheric Administration and the Environmental Protection Agency. After the designation of the sanctuary and its research mandate, workshops were held to cross disciplines and to identify research needs (Strickland 1996, Bowlby et al. 2001). More recently, several groups have worked at coastwide, state, and local scales to identify research priorities for Washington's outer coast.

- The Washington State Ocean Policy Work Group published their final report in 2006, *Washington's Ocean Action Plan*, which analyzed the condition of ocean resources, their contributions to the state's character, quality of life, and economic viability (Washington State Ocean Policy Work Group 2006). Based on their analysis of the status of Washington's ocean resources and coastal communities, they issued recommendations that include monitoring or research priorities for coastal ecosystems.

- The Sea Grant organizations from California, Oregon, and Washington collaborated on a series of workshops across the entire coast to collect stakeholder's perspectives on information and research needs to effectively manage the coast, published in *West Coast Regional Marine Research and Information Needs* (Risien 2009). In the course of these stakeholder workshops, research and information priorities unique to Washington State were identified but not included in the final multi-state document. Representative comments specific to Washington are provided in the tables below.

- As part of the Olympic Coast National Marine Sanctuary management plan review process, the sanctuary drafted 20 Action Plans pertaining to management, research, education, conservation, and socioeconomics (Olympic Coast National Marine Sanctuary 2011). The revised management plan will replace the one created in 1994 when the sanctuary was designated.

Across their differing memberships, scales of focus, and jurisdictions, the groups described above came to very similar conclusions about monitoring and research priorities for Washington's outer coast (summarized in Tables 3-13). Two key needs are for ecosystem-based management and spatially explicit marine planning.

Ecosystem-based Management

Despite a general agreement about the need for an ecosystem-based approach across public and private sectors and across state and regional agencies, Washington's outer coast lacks a governance structure for setting indicators and thresholds for ecosystem health or for setting policy objectives to assess status and work towards meeting management goals at an ecosystem scale. Some work to document the current condition of coastal resources has been done, focusing on the north outer coast. The Olympic Coast National Marine Sanctuary assessed the threats to sanctuary resources in its 2008 Condition Report according to the system-wide monitoring protocol of the National Marine Sanctuary System, which relies on surveys of experts but does not integrate local or regional stakeholders in identifying appropriate indicators or setting the thresholds for desired ecosystem states (Office of National Marine Sanctuaries 2008). Without indicators and thresholds, a data-driven, quantitative analysis of the status of coastal ecosystems – and adaptive management to move the ecosystem towards a more desirable state – would have no reference points to understand the current condition or the consequences of management actions. A Washington State example might be found in the Puget Sound Partnership (http://www.psp.wa.gov/), which is leading an ecosystem-based approach to management of Washington's inner marine waters (the Salish Sea) following an integrated ecosystem assessment approach (Levin et al. 2009). Covering the West Coast region, an integrated ecosystem assessment for the entire West Coast is the focus of one of the seven Action Coordination Teams of the West Coast Governors' Agreement on Ocean Health.

Integrated ecosystem assessment comprises several steps: scoping, indicator development, risk analysis, management strategy evaluation, and monitoring and evaluation (Levin et al. 2009). Stakeholder involvement, such as that engendered by the Sea Grant workshops (Risien et al. 2009), demonstrates considerable interest by the community and potential for success in the first step, scoping, which identifies societal objectives and threats relating to the ecosystem. Next, indicators must be developed to assess the status and trends in the state of the ecosystem. Tallis et al. (2010) emphasized the need to establish thresholds for each ecosystem indicator, likely requiring modeling and simulation to establish a "health" level for the indicator. The next step, risk analysis, often uses ecosystem modeling to quantify the status of ecosystem indicators. Management strategy evaluation can then be used to help identify policies and methods to meet ecosystem objectives. Following the adaptive management model, ongoing monitoring and evaluation is needed to determine which strategies are working and what changes are needed.

Although social and natural scientific knowledge about the outer coast ecosystem has gaps and weak areas, it is not the impediment to moving towards a more integrated ecosystem-based approach (Lester et al. 2010). Examples of comprehensive ecosystem-based management in marine settings are not common, but regional efforts are making progress in this direction. Ruckelshaus and colleagues provide basic principles to use along the way: define the spatial boundaries of the marine ecosystem to be managed, develop a clear statement of objectives, include humans in the characterizations of marine ecosystems and indicators of their response to change, use a variety of strategies to hedge against uncertainty in ecosystem responses, use spatial frameworks such as zoning for coordinating multiple management sectors and approaches, and link the governance structure with the scale of the ecosystem elements to be managed (Ruckelshaus et al. 2008). Preliminary actions towards all six of these steps have been taken, but more work is needed to provide the governance structure and specific objectives to guide the process.

Marine Spatial Planning

Another key priority emerging from Tables 3-13 is the need to transition to a spatially explicit, ecosystem-scale approach to managing natural resources and human uses of the outer coast. New needs such as marine-based renewable energy generation are emerging in possible conflict with existing activities and new threats such as climate change are altering physical and biological processes. As of March 2010, Washington State became one of two states with legislation requiring marine spatial planning (SB 6350). State management agencies responded to the need identified by the legislature with a framework for planning, goals and objectives, and management and information needs for coastal and marine spatial planning in Washington State (Henessey and State Ocean Caucus 2011). The report calls for proactive, comprehensive, and ecosystem-based planning to balance renewable energy demands with aquaculture, marine transportation, oil and gas development, protection of sentitive habitats, scientific research, sediment management, telecommunications, new fisheries, military activities, and recreation and tourism. A comprehensive marine management plan envisioned by the report will require research to provide spatial data on natural science questions of physical, chemical, and biological aspects of the marine environment, as well as human use, management, and infrastructure data. Research will also be needed to establish coordinated, coast-wide indicators as part of an ecosystem assessment. These needs largely duplicate those already found in Tables 3-13. The report identifies the lack of a cross-jurisdictional coordinating body to oversee the needed research and implementation as a key impediment to spatially explicit, ecosystem-scale planning for Washington's coast.

Tables 3-13 summarize the specific research needs identified by the West Coast Sea Grant workshops (including needs expressed specific to Washington State), the State Ocean Caucus Ocean Action Plan, and the Olympic Coast National Marine Sanctuary Management Plan Review. Topics are organized by the areas of research focus identified by Risien (2009): climate change, ocean education and environmental literacy, access to information and data, vitality of coastal communities and maritime operations, ocean and coastal governance and management of multiple uses, fisheries and aquaculture, water quality and pollution, marine ecosystem structure and function, ocean health and stressors, physical ocean processes, and resilience and adaptability. The tables are not intended to be a full summary of the recommendations of each report, which also include administrative, education, and outreach activities. Although these activities are vital to improving coastal management, the tables below highlight recommendations calling specifically for new or intensified research in the natural and social sciences.

TABLE 3: RESEARCH NEEDS: CLIMATE CHANGE.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Frame research in context of climate change o Improve models and forecasts
Washington Sea Grant Stakeholder Workshops	o Investigate ocean acidification and water temperature changes o Research climate effects on productivity, food webs, invasive alien species, and harmful algal blooms, and the distribution and abundance of protected and harvested species
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Climate Change (Ch. 2)	o Conduct research to predict impacts and vulnerabilities and to adapt resource planning, mitigation, and management
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Physical and Chemical Oceanography Action Plan • Climate Action Plan	o Monitor and model carbonate system variables to improve understanding of extent and severity of ocean acidification o Research the effects of climate change on calcifying and non-calcifying organisms including deep sea corals, plankton, intertidal invertebrates, and on trophic relationships between these species o Establish the sanctuary as a sentinel site for long-term climate change research and monitoring o Identify marine chemical, physical, and biological indicators of climate change

TABLE 4: RESEARCH NEEDS: OCEAN EDUCATION AND ENVIRONMENTAL LITERACY.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Professional training, educational resources and evaluation methods
Washington Sea Grant Stakeholder Workshops	o Study and enhance effectiveness of K-12 environmental education efforts o Involve citizens in science activities
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Ocean Education (Ch. 4)	o Develop ocean education inventory and strategic plan
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Higher Education Action Plan	o Coordinate internships, volunteer positions, and partnerships with universities for opportunities for students to be involved in marine research

TABLE 5: RESEARCH NEEDS: ACCESS TO INFORMATION AND DATA.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Increase compatibility of datasets o Develop tools and applications for non-technical users o Support information integration and synthesis
Washington Sea Grant Stakeholder Workshops	o Improve data access, coordination, standards, and sharing
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Ocean Research and Observing (Ch. 4)	o Collaborate with Oregon and California on ocean research, monitoring and observing o Expand radar, buoys, and other sensors and integrate observing networks
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Habitat Mapping and Classification Action Plan • Data Management, Sharing and Reporting Action Plan	o Produce standardized seafloor habitat classification maps in GIS and other user-friendly formats o Develop an adaptive management process to periodically evaluate data-collection efforts o Publish regular reports on the condition of ecological resources

TABLE 6: RESEARCH NEEDS: VITALITY OF COASTAL COMMUNITIES AND MARITIME OPERATIONS.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Develop cost/benefit analyses to balance economic growth and sustainable natural resource use o Develop social and economic indicators to characterize maritime infrastructure and operations
Washington Sea Grant Stakeholder Workshops	o Develop socio-economic and ecosystem services models o Create a long-term social and cultural vision for the region o Strengthen oil spill response
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Sustainable Economy (Ch. 5)	o Help communities implement development projects, assist local planning efforts, promote infrastructure and economic development o Update economic vitality index for coastal communities, promote linkages between research and economies
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Maritime Heritage Action Plan • Socioeconomic Values of Sanctuary Resources Action Plan	o Locate, inventory, assess, interpret, and protect cultural resources in the sanctuary o Gather, share, and apply traditional ecological knowledge, local and customary knowledge, and cultural resource analyses o Foster analysis and dissemination of existing socioeconomic data about Olympic coast marine resources and human use patterns, including an annotated bibliography and user-friendly GIS layers o Develop partnerships with the coastal treaty tribes and other groups to collect, assemble, and analyze new information about human activities occurring in the sanctuary and their socioeconomic values

TABLE 7: RESEARCH NEEDS: OCEAN AND COASTAL GOVERNANCE AND MANAGEMENT OF MULTIPLE USES.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Conduct integrated ecosystem assessments o Evaluate and improve institutional capabilities and policies
Washington Sea Grant Stakeholder Workshops	o Assess impacts of offshore tidal, wave, and wind power generation and nearshore armoring o Reearch on nearshore restoration
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Ecosystem-based Management, Ocean Energy (Ch. 1)	o Assess coastal and ocean resources and trends to facilitate an ecosystem-based management approach and develop appropriate management tools o Evaluate potential impacts of renewable energy on existing uses and investigate developing comprehensive guidelines for renewable ocean energy (such as a programmatic environmental impact statement)
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Populations, Communities, and Ecosystems Action Plan • Marine Spatial Planning Action Plan	o Evaluate ecosystem status and trends for use in management o Identify, prioritize, and collect spatial data of marine uses and resources, along with existing sanctuary data, and make available to regional spatial planning efforts

TABLE 8: RESEARCH NEEDS: FISHERIES AND AQUACULTURE.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Research social and economic impacts and benefits of fisheries and aquaculture o Research interactions with ecosystems o Evaluate alternative management approaches
Washington Sea Grant Stakeholder Workshops	o Conduct stock assessments and research fish ecology o Research wildlife health and toxicology o Characterize human consumption and exposure o Evaluate and communicate seafood sustainability
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Aquaculture (Ch. 1)	o Research physical and socioeconomic effects of marine fish enhancements and finfish aquaculture
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Collaborative and Coordinated Sanctuary Management Action Plan • Habitat Protection Action Plan	o Collaborate to develop criteria for and locate habitat types of special importance to ecosystem function or managed species o Develop and implement strategies for protection of habitats of special ecosystem value o Identify and review recommendations for essential fish habitat and habitat areas of particular concern

TABLE 9: RESEARCH NEEDS: WATER QUALITY AND POLLUTION.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Investigate sources, transport, fate, and prevention of contaminants between nearshore and offshore areas o Characterize health impacts of poor water quality o Develop indicators, methods, and tools to monitor water quality and institute preventive measures
Washington Sea Grant Stakeholder Workshops	o Research emerging pollutants, including endocrine disruptors, waste treatment, ruoff from communities and roads, oil spills and dispersants, and atmospheric deposition
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Marine Debris, Oil spills (Chapter 3)	o Identify and remove derelict fishing gear o Improve oil spill prevention, preparedness, and response
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Physical and Chemical Oceanography Action Plan • Spills Prevention, Preparedness, Response, and Restoration Action Plan • Water Quality Protection Action Plan	o Continue coastal water quality monitoring of temperature, salinity, dissolved oxygen, currents, and chlorophyll o Review, develop, and improve Geographic Response Plans to protect cultural resources and shorelines o Develop guide for treatment tactics and cleanup endpoints for affected shorelines o Propose monitoring and other requirements for sensitive resources and habitats o Help compile spatial and temporal data on oil dispersant use and potentially affected water column natural resources o Develop plans, protocols, capacity, and baseline data on natural and cultural resources to improve natural resource damage assessments o Assess wastewater discharges from large vessels o Monitor contaminant levels, research their impacts, and reduce, eliminate, or mitigate those impacts on natural resources in the sanctuary

TABLE 10: RESEARCH NEEDS: MARINE ECOSYSTEM STRUCTURE AND FUNCTION.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Research variation of near and offshore ocean conditions o Characterize the ecological structure and function of nearshore marine ecosystem influences bay, river mouth, and estuary habitats and communities, benthic and geomorphic features and communities, and marine food webs o Determine appropriate ecological indicators o Relate predators, fisheries, physio-chemical conditions and effects of predator removals on food web o Identify biodiversity shifts o Evaluate marine protected area potential o Research and implement ecological restoration
Washington Sea Grant Stakeholder Workshops	o Characterize community structure and trophic interactions o Investigate migratory species' population connectivity and marine mammal and seabird ecology and conservation o Perform large-scale, long-term monitoring, mapping (deep and shallow water) and habitat characterization o Study deep coral communities o Research protected-species ecology and management and multi-species management o Identify indicator species o Characterize connections to freshwater and upland ecosystems o Conduct historical analyses of climate impacts
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Ocean Research and Observing (Chapter 4)	o Collaborate on benthic habitat research efforts, including nearshore and shelf habitat characterization and mapping

Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Habitat Mapping and Classification Action Plan • Populations, Communities, and Ecosystems Action Plan	o Increase the area of the sanctuary that is mapped using recognized survey protocols and data standards o Monitor pelagic larval phases of species of commercial and ecological significance and pelagic zooplankton and fish abundances o Survey, monitor, and report on sand and rocky intertidal, subtidal, and benthic zones, and develop indicator species and parameters to measure stressors o Better characterize health of and changes affecting the distribution, abundance, productivity, and spawning areas of fish species and populations o Better characterize spatial and temporal abundance, foraging areas, migration, and key habitat of marine birds and mammals o Evaluate indicator species currently used by sanctuary and regional partners for monitoring and the sanctuary's Condition Report, considering trophic connections and coupling of biological and physical systems o Evaluate research and monitoring priorities for a revised set of indicator species

TABLE 11: RESEARCH NEEDS: OCEAN HEALTH AND STRESSORS.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Investigate causes, dynamics, risks, and ecological, social, and economic effects of ocean stressors such as aquatic invasive species, harmful algal blooms, and hypoxia
Washington Sea Grant Stakeholder Workshops	o Characterize ecological and economic impacts of invasive alien species and research prevention of invasion o Research effects of climate on invasive alien species distributions o Conduct prediction and monitoring of harmful algal blooms o Determine causes and effects of low dissolved oxygen levels o Investigate cumulative impacts of multiple stressors
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Ecosystem-based Management (Ch.1)	o Develop performance measures and key indicators to evaluate progress toward ecosystem health.
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Physical and Chemical Oceanography Action Plan • Habitat Protection Action Plan	o Research the distribution, causes, and ecological effects of hypoxic conditions in marine waters o Monitor, detect, understand, and predict harmful algal blooms and their impacts on natural resources and humans o Identify threats, impacts, and relative vulnerability of physical and biogenic habitats and monitor for impacts, including cumulative effects o Monitor the recovery rates of habitats, communities, and habitat-forming biogenic structure following disturbance by human activities o Monitor for presence and abundance of invasive species and support regional efforts to respond and reduce ecological and economic impacts

Table 12: Research needs: Physical ocean processes, related climate change, and physical coastal hazards.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Characterize ocean circulation and acidification o Model physical-ecological interactions o Research sediment movement
Washington Sea Grant Stakeholder Workshops	o Characterize dynamics and ecosystem impacts (including linked mechanistic models) of ocean acidification, low dissolved oxygen levels, and sea level change o Model hydrodynamics, erosion, and sediment transport o Assess potential for carbon sequestration o Conduct long-term monitoring of oceanographic variables and wave conditions o Model climate change impacts on fished species
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Coastal Hazards; Coastal Erosion and Sediment Management (Ch. 2)	o Address gaps in hazards research and planning and advance baseline data and research on coastal hazards conducted by state agencies o Conduct long-term sediment and erosion monitoring and modeling with independent analysis
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Physical and Chemical Oceanography Action Plan	o Monitor and model carbonate system variables to improve understanding of the extent and severity of ocean acifidification

TABLE 13: RESEARCH NEEDS: RESILIENCE AND ADAPTABILITY TO HAZARDS AND CLIMATE CHANGE.

Initiative or source document	Research needs identified
West Coast Regional Marine Research and Information Needs (Risien 2009)	o Assess vulnerability of social and ecological systems to coastal natural hazards o Research prediction, mitigation, adaptation, and response strategies o Characterize resilient behavior of social and ecological systems
Washington Sea Grant Stakeholder Workshops	o Conduct local mapping of sea-level rise o Study impact of dam removal on nearshore ecosystems o Identify restoration targets o Research risk perception and human behavior o Link ecological and economic models to predict value of restoration
Washington's Ocean Action Plan (Washington State Ocean Policy Work Group 2006) • Natural Hazards; Climate Change (Ch. 2)	o Analyze effectiveness of shoreline policies o Conduct climate research necessary to predict impacts and vulnerabilities and adapt resource planning, mitigation, and management
Olympic Coast National Marine Sanctuary Management Plan Review (Olympic Coast National Marine Sanctuary 2011) • Climate Change Action Plan	o Develop projections for local sea level rise and impacts to natural and cultural resources

Acknowledgements

The editors gratefully acknowledge the contributing authors and reviewers who made this document possible. We also extend our gratitude to the Washington Sea Grant Program for providing their database of stakeholder comments from workshops about coastal research and information needs in Washington during 2007 and 2008. Many other individuals also provided important suggestions that contributed to the drafting and revision of this document, including species experts that contributed to the species accounts available on the Washington Department of Fish and Wildlife web site.

Jim Ames	Washington Department of Fish and Wildlife
Dan Ayres	Washington Department of Fish and Wildlife
Greg Bargmann	Washington Department of Fish and Wildlife
Helen Berry	Washington Department of Natural Resources
Brady Blake	Washington Department of Fish and Wildlife
Ed Bowlby	Olympic Coast National Marine Sanctuary
Andy Carlson	Washington Department of Fish and Wildlife
Mick Cope	Washington Department of Fish and Wildlife
Marc Daily	Washington Department of Fish and Wildlife
Dan Doty	Washington Department of Fish and Wildlife
Brett Dumbauld	Washington Department of Fish and Wildlife
Dale Gombert	Washington Department of Fish and Wildlife
Tom Jagiello	Washington Department of Fish and Wildlife
Steven Jeffries	Washington Department of Fish and Wildlife
Terry Johnson	Washington Department of Fish and Wildlife
Don Kraege	Washington Department of Fish and Wildlife
Curt Leigh	Washington Department of Fish and Wildlife
Dick Logan	Washington Department of Ecology
Mary Lou Mills	Washington Department of Fish and Wildlife
Diane Mitchell	Washington State Library

David Mudd	Washington Department of Fish and Wildlife
Jon Neel	Washington Department of Ecology
Corey Niles	Washington Department of Fish and Wildlife
Dave Nysewander	Washington Department of Fish and Wildlife
Dick O’Connor	Washington Department of Fish and Wildlife
Kevin Ryan	National Refuge Program, U.S. Fish and Wildlife Service
Camille Speck	Washington Department of Fish and Wildlife
Charles Stenvall	National Refuge Program, U.S. Fish and Wildlife Service
Julie Stofel	Washington Department of Fish and Wildlife
Chris Thompson	Washington Department of Fish and Wildlife
Eric Wagner	Department of Biology, University of Washington
Walter Wakefield	National Marine Fisheries Service
Farren Wallace	Washington Department of Fish and Wildlife
Michelle Wainstein	Washington Sea Grant
Lorna Wargo	Washington Department of Fish and Wildlife
Jim West	Washington Department of Fish and Wildlife

References

Allan, J.C. and P.D. Komar. 2006. Climate controls on US West Coast erosion processes. *Journal of Coastal Research* 22(3):511-529.

Anderson, D.W., F. Gress, and D.M. Fry. 1996. Survival and dispersal of oiled Brown Pelicans after rehabilitation and release. *Marine Pollution Bulletin* 32:711-718.

Antrim, L.D., R.M. Thom, W.W. Gardiner, V.I. Cullinan, D.K. Shreffler and R.W. Bienert. 1995. Effects of petroleum products on bull kelp (*Nereocystis luetkeana*). *Marine Biology* 122:23-31.

Baker, P. 1995. Review of Ecology and Fishery of the Olympia oyster, *Ostrea lurida*, with annotated bibliography. *Journal of Shellfish Research* (14):501-518.

Bakun, A. 1990. Global climate change and intensification of coastal ocean upwelling. *Science* 247:198-201.

Bakun, A. 2006. Wasp-waist populations and marine ecosystem dynamics: Navigating the "predator pit" topographies. *Progress in Oceanography* 68:271-288.

Bakun, A., D. B. Field, A. Redondo-Rodriguez, and S. J. Weeks. 2010. Greenhouse gas, upwelling-favorable winds, and the future of coastal ocean upwelling ecosystems. *Global Change Biology* 16:1213-1228.

Bakun, A. and S.J. Weeks. Greenhouse gas buildup, sardines, submarine eruptions and the possibility of abrupt degradation of intense marine upwelling ecosystems. *Ecology Letters* 7:1015-1023.

Batchelder, H.P. and Powell, T.M. 2002. Physical and biological conditions and processes in the northeast Pacific Ocean. *Progress in Oceanography* 53:105-114.

Bauer, M., P. Hoagland, T.M. Leschine, B.G. Blount, C.M. Pomeroy, L.L. Lampl, C.W. Scherer, D.L. Ayres, P.A. Tester, M.R. Sengco, K.G. Sellner, J. Schumacker. 2010. The importance of human dimensions research in managing harmful algal blooms. *Frontiers in Ecology and the Environment* 8 (2):75-83.

Beauchamp, K. A., and M. M. Gowing. 1982. A quantitative assessment of human trampling effects on a rocky intertidal community. *Marine Environmental Research* 7:279-293.

Berry, H.D., J.R. Harper, T.F. Mumford, Jr., B.E. Bookheim, A.T. Sewell, and L.J. Tamayo. 2001. *The Washington State ShoreZone Inventory User's Manual*. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia, WA. Retrieved 20 September 2010 from http://www.dnr.wa.gov/Publications/aqr_nrsh_szusermanual.pdf

Berry, H.D., T.F. Mumford, P. Dowty. 2005. Using historical data to estimate changes in floating kelp (*Nereocystis luetkeana* and *Macrocystis integrifolia*) in Puget Sound, Washington. Presented at the Puget Sound/Georgia Basin Research Conference in Seattle, WA.

Booth, D.M. and K.L. Heck. 2009. Effects of the American oyster *Crassostrea virginica* on growth rates of the seagrass *Halodule wrightii*. *Marine Ecology Progress Series* 389:117-126.

Borde, A.B., R.M. Thom, S. Rumrill, and L.M. Miller. 2003. Geospatial habitat analysis in Pacific Northwest Coastal Estuaries. *Estuaries* 26(4B):1104-1116.

Bourgeron, P.S. 1988. Advantages and limitations of ecological classification for the protection of ecosystems. *Conservation Biology* 2:218-220.

Bowlby, C.E., B.A. Blackie, and J.K. Parrish (eds). 2001. *Olympic Coast National Marine Sanctuary: Proceedings of the 1998 Research Workshop, Seattle, Washington*. Marine Sanctuaries Conservation Series MSD-01-04. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Marine Sanctuaries Division, Silver Spring, MD.

Brancato, M.S., C.E. Bowlby, J. Hyland, S.S. Intelmann, and K. Brenkman. 2007. *Observations of deep coral and sponge assemblages in Olympic Coast National Marine Sanctuary, Washington*. *Cruise report: NOAA Ship McArthur II Cruise AR06-06/07.* Marine Sanctuaries Conservation Series NMSP-07-03. U.S. Department of Commerce, National Oceanic and Atmostpheric Administration, National Marine Snctuary Program, Silver Spring, MD.

Britton-Simmons, K.H. 2004. Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. *Marine Ecology Progress Series* 277:61-78.

Brosnan, D. M. and L. L. Crumrine. 1994. Effects of human trampling on marine rocky shore communities. *Journal of Experimental Marine Biology and Ecology* 177:79-97.

Buchanan, J.B., D.H. Johnson, E.L. Greda, G.A. Green, T.R. Wahl, and S.J. Jeffries. 2001. Wildlife of coastal and marine habitats. In D.H. Johnson and T.A. O'Neil (managing directors). *Wildlife-habitat relationships in Oregon and Washington*. Oregon State University Press, Corvallis, Oregon.

Buckley, R.M and L.L. LeClair. 1999. *1997 and 1998 Sampling of Drifting Algae and Seagrass Habitats in the Olympic Coast National Marine Sanctuary, Washington: Distribution of Drifting Habitats*. A Report to Washington Department of Fish and Wildlife. Washington Department of Fish and Wildlife, Olympia, Washington.

Budinger, T.F., L.K. Coachman, and C.A. Barnes. 1964. *Columbia River effluent in the Northeast Pacific Ocean; 1961, 1962: Selected aspects of physical oceanography*. Tech. Rept. No. 99. Department of Oceanography, University of Washington, Seattle.

Christy, J.A. and J. A. Putera. 1993. *Lower Columbia River natural area inventory*. Oregon Natural Heritage Program. Report to The Nature Conservancy, Washington Field Office, Seattle.

Climate Impacts Group, 2009. *The Washington Climate Change Impacts Assessment.* M. McGuire Elsner, J. Littell, and L Whitely Binder (eds). Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, Washington. Retrieved 20 September 2010 from http://www.cses.washington.edu/db/pdf/wacciareport681.pdf

Cohen, A.N., H.D. Berry, C.E. Mills, D. Milne, K. Britton-Simmons, M.J. Wonham, D.L. Secord, J.A. Barkas, B. Bingham, B.E. Bookheim, J.E. Byers, J.W. Chapman, J.R. Cordell, B. Dumbauld, A. Fukuyama, L.H. Harris, A.J. Kohn, K. Li, T.F. Mumford Jr., V. Radashevsky, A.T. Sewell, and K. Welch. 2001. *Washington State Exotics Expedition 2000: A Rapid Survey of Exotic Species in the Shallow Waters of Elliot Bay, Totten and Eld Inlets and Willapa Bay (2001)*. Report Prepared for the Nearshore Habitat Program, Aquatic Resources Division, Washington State Department of Natural Resources, Olympia, WA.

Collins, D.P. and R.E. Trost. 2010. *2010 Pacific Flyway data book: Waterfowl harvests and status, hunter participation and suces in the Pacific Flyway and United States*. U.S. Fish and Wildlife Service, Portland, OR.

Connolly, S.R. and J. Roughgarden. 1998. A latitudinal gradient in northeast Pacific intertidal community structure: evidence for an oceanographically based synthesis of marine community theory. *American Naturalist* 151:311-326.

Conan, G. 1982. The long-term effects of the Amoco Cadiz oil spill. In: *The Long-Term Effects of Oil Pollution on Marine Populations, Communities, and Ecosystems*. Proceedings of the Royal Society Discussion Meeting, October 1981 (R.B. Clarke, Ed), pp. 139-147. The Royal Society, London.

Cook, A.E., J.A. Shaffer, B.R. Dumbauld, and B.E. Kauffman. 2000. A plan for rebuilding stocks of Olympia oysters (*Ostreola conchaphila*, Carpenter 1857) in Washington State. *Journal of Shellfish Research* 19(1):409-412.

Cordell, J.R., C.A. Simenstad, B. Feist, K.L Fresh, R.M. Thom, D.J. Stouder and V. Luiting. 1998. Ecological effects of *Spartina alterniflora* invasion of the Littoral Flat Community in Willapa Bay, Washington. Abtracts from the Eight International Zebra Mussel and Other Nuisance Species Conference, Sacramento, California March 16-19, 1998.

Cordell, J.R., L.M. Tear, and S.M. Bollens. 2010. Modelling physic-chemical factors affecting occurrences of a non-indegenous planktonic copepod in northeast Pacific estuaries. *Biological Invasions* 12 (5):1427-1445.

Costanza, R., R.d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannum, K. Limburg, and S. Naeem. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. *Classification of wetlands and deepwater habitats of the United States*. U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Culberston, J.B., I. Valiela, M. Pickart, E.E. Peacock, and C.M. Reddy. 2008. Long-term consequences of residual petroleum on salt marsh grass. *Journal of Applied Ecology* 45(4):1284-1292.

Cullinan, T. 2001. *Important Bird Areas of Washington*. Audubon Washington, Olympia, Washington.

Dayton, P.K. 1975. Experimental evaluation of ecological dominance in a rocky intertidal algal community. *Ecological Monographs* 45:137-159.

Department of the Navy. 2010. Northwest Training Range Complex Environmental Impact Statement. Retrieved 03 April 2011 from http://www.nwtrangecomplexeis.com/.

Dethier, M.N. 1989. *A survey of intertidal communities of the Pacific Coastal Area of Olympic National Park, Washington*. Final Report. Friday Harbor Laboratories.

Dethier, M.N. 1990. *A Marine and Estuarine Habitat Classification System for Washington State*. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Dethier, M.N. 1991. *The Effects of an Oil Spill and Freeze Event on Intertidal Community Structure in Washington, Final Report*. OCS Study MMS 91-0002.

Dethier, M.N. 1992. Classifying marine and estuarine natural communities: an alternative to the Cowardin system. *Natural Areas Journal* 12(2):90-100.

Dethier, M.N. 2002. Biological Units. *In* Murray, S.N., R.F. Ambrose, and M.N. Dethier. *Methods for performing monitoring, impact, and ecological studies on rocky shores*. OCS Study MMS 01-070.

Dethier, M.N. and S. Deering. 1996. *Inventory and monitoring of edible intertidal invertebrates on the Olympic Coast of Washington: Final Report*. Submitted to the National Park Service, March 1996.

Dethier, M.N., D.O. Duggins, and T.F. Mumford. 1989. Harvesting of non-traditional marine resources: trends and concerns. *Northwest Environmental Journal* 5:71-87.

Dethier, M.N., K. McDonald and R.R. Strathmann. 2003. Colonization and connectivity of habitat patches for coastal marine species distant from source populations. *Conservation Biology* 17:1024-1035.

Duggins, D.O., J.E. Eckman. 1994. The role of kelp detritus in the growth of benthic suspension feeders in an understory kelp forest. *Journal of Experimental Marine Biology and Ecology* 176:53-68.

Duggins, D.O., C.A. Simenstad, J.A. Estes, 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. *Science* 245:170-173.

Dumbauld, B.R., J.L. Ruesin, and S.S. Rumrill. 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: A review with application to oyster and clam cultue in West Coast (USA) estuaries. *Aquaculture* 290:196-223.

Dyson, K. and D.D. Huppert. 2010. Regional economic impacts of razor clam beach closures due to harmful algal blooms (HABS) on the Pacific coast of Washington. *Harmful Algae* 9:264-271.

Ebert, T.A. and M.P. Russell. 1988. Latitudinal variation in size structure of the west coast purple urchin: a correlation with headlands. *Limnology and Oceanography* 33:286-294.

Eckman, J.E., D.O. Duggins, and A.T. Sewell. 1989. Ecology of understory kelp environments. 1. Effects of kelps on flow and particle transport near the bottom. *Journal of Experimental Marine Biology and Ecology* 129(2):173-187.

Edwards, M.G., Beaugrand, G.C. Hays, J.A. Koslow, and A.J. Richardson. 2010. Multi-decadal oceanic ecological datasets and their application in marine policy and management. *Trends in Ecology and Evolution* 25:602-610.

Elston, R. 1997. *Pathways and management of marine nonindigenous species in the shared waters of British Columbia and Washington*. Puget Sound/Georgia Basin Environmental Report Series: Number 5. Prepared for the Puget Sound/Georgia Basin International Task Force, Work Group on Minimizing Introductions of Exotic Species, with support from Puget Sound Water Quality Action Team, U.S. EPA Region 10, Department of Fisheries and Oceans, Canada, and the Washington Department of Ecology.

Erickson, A. 2005. *Effect of human trampling in the barnacle zone along a gradient of use in Olympic National Park*. MS Thesis, School of Marine Affairs, University of Washington.

Estes, J.A. and J.F. Palmisaon. 1974. Sea otters: Their role in structuring Nearshore Communities. *Science* 185(4156):1058-1060.

Estes, J.A., E.M. Danner, D.F. Doak, B. Konar, A.M. Spring, P.D. Steinberg, M.T. Tinker, and T.M. Williams. 2004. Complex trophic interactions in kelp forest ecosystems. *Bulletin of Marine Science* 74(3):621-638.

Etnoyer, P. and L. Morgan. 2003. *Occurrences of habitat-forming deep sea corals in the northeast Pacific Ocean*. Marine Conservation Biology Institute, Redmond, WA and National Oceanic Atmospheric Administration, Silver Spring MD.

Feldman, K., D. Armstrong, B. Dumbault, T. DeWitt and D. Doty. 2000. Oysters, crabs, and burrowing shrimp: review of an environmental conflict over aquatic resources and pesticide use in Washington state’s (US) coastal estuaries. *Estuaries* 23:141-176.

Fish and Wildlife Commission. 1998. *Forage fish management policy, goals, and plan*. Fish and Wildlife Commission Policy Decision POL-C3012.

Fleming, S.P., D.C. Roland, P.C. Smith, P.J. Austin-Smith, and R.P. Bancroft. Piping plover status in Nova Scotia related to its reproductive and behavioral responses to human disturbance. *Journal of Field Ornithology* 59(4):321-330.

Ford, R.G., D.H. Varoujean, D.R. Warrick, W.A. Williams, D.B. Lewin, C.L. Hewitt, and J.L. Casey. 1991. Seabird Mortality Resulting from the Nestucca Oil Spill Incident Winter 1988-89. Final Report. Prepared for the Washington Department of Fish and Wildlife.

Franklin, J.F. and C.T. Dyrness. 1988. *Natural Vegetation of Oregon and Washington*. Oregon State University Press, Corvallis.

Gaines, S.D. and J. Roughgarden. 1987. Fish in offshore kelp forests affect recruitment to intertidal barnacle populations. *Science* 235(4787):479-481.

Gjerdrum C, A.M. Vallée, C.C. St Clair, D.F. Bertram, J.L. Ryder, and G.S. Blackburn. 2003. Tufted puffin reproduction reveals ocean climate variability. *Proceedings of the National Academy of Sciences* 100(16):9377-82.

Gonzalez, J., F.G. Figueiras, M. Aranguren-Gassis, B.G. Crespo, E. Fernandez, X.A.G. Moran, and M. Nieto-Cid. 2009. Effect of a simulated oil spill on natural assemblages of marine phytoplankton enclosed in microcosms. *Estuarine Coastal and Shelf Science* 83(3):265-276.

Halpern, B.S., S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J.F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E.M.P. Madin, M T. Perry, E.R. Selig, M. Spalding, R. Steneck, and R. Watson. 2008. A global map of human impact on marine ecosystems. *Science* 319:948-952.

Halpern, B.S., C.V. Kappel, K.A. Selkoe, F. Micheli, C.M. Ebert, C. Kontgis, C.M. Crain, R.g.Martone, C. Shearer, and S.J. Teck. 2009. Mapping cumulative human impacts to California Curent marine ecosystems. *Conservation Letters* 2:138-148.

Hamel, N.H., J.K. Parrish, J. Laake. 2008. Linking colonies to fisheries: Spatio-temporal overlap between common murres (*Uria aalge*) from Tatoosh Island and coastal gillnet fisheries in the Pacific Northwest, USA. *Biological Conservation* 141:3101-3115.

Harper, J.R., D.E. Howes and P. D. Reimer 1991. Shore-zone mapping system for use in sensitivity mapping and shoreline countermeasures. In: *Proceedings of the 14th Arctic and Marine Oilspill Program (AMOP) Technical Program,* p. 509-523. Environment Canada.

HARRNESS. 2005. *Harmful Algal Research and Response: A National Environmental Science Strategy 2005–2015*. Ramsdell, J.S., D.M. Anderson and P.M. Glibert (Eds.), Ecological Society of America, Washington DC.

Helmuth, B., R.R. Veit, and R. Holberton. 1994. Long-distance dispersal of a subarctic brooding bivalve (*Gaimardia trapesina*) by kelp-rafting. *Marine Biology* 120:421-426.

Hennessey, J. and the State Ocean Caucus. 2011. Marine Spatial Planning in Washington: Final Report and Recommendations of the State Ocean Caucus to the Washington State Legislature. Washington Department of Ecology, Olympia, WA.

Hickey, B.M. and N.S. Banas. 2003. Oceanography of the U.S. Pacific Northwest Coastal Ocean and Estuaries with Applications to Coastal Ecology. *Estuaries* 26(4B):1010-1031.

Hickey, B.M. and N.S. Banas. 2008. Why is the northern end of the California Current System so productive? *Oceanography* 21(4):90-107.

Hickey, B., S. Geier, N. Kachel, and A. MacFayden. 2005. A bi-directional river plume: The Columbia in summer. *Continental Shelf Research* 25:1631-1656.

Howes, D.E., J.R. Harper and E.H. Owens. 1994. *British Columbia physical shore-zone mapping system*. The Coastal Task Force of the Resource Inventory Committee (RIC), RIC Secretariat. Victoria, B.C.

Huff, Mark H.; Raphael, Martin G.; Miller, Sherri L.; Nelson, S. Kim; Baldwin, Jim, tech. coords. 2006. *Northwest Forest Plan—The first 10 years (1994-2003): status and trends of populations and nesting habitat for the marbled murrelet*. Gen. Tech. Rep. PNW-GTR-650. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Huppert, D.D., A. Moore, and K. Dyson. 2009. Impacts of climate change on the coasts of Washington State. In: Littell, J.S., M. McGuire Elsner, L.C.Whitely Binder, and A.K. Snover (eds). Chapter 8 in: *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*. Climate Impacts Group, University of Washington. Seattle, WA.

Ingolfsson, A. 1998. Dynamics of macrofaunal communities of floating seaweed clumps off western Iceland: a study of patches on the surface of the sea. *Journal of Experimental Marine Biology and Ecology* 231:119-137.

IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, Pachauri, R.K and Reisinger, A., Eds.). IPCC, Geneva, Switzerland.

Jackson, J.B.C et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629-638.

Jameson, R.J. and S. Jeffries. 2007. *Results of the 2007 survey of the reintroduced sea otter population in Washington State*. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA.

Jameson, R.J. and S. Jeffries. 2008. *Results of the 2008 survey of the reintroduced sea otter population in Washington State*. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA.

Jameson, R.J. and S. Jeffries. 2010. *Results of the 2010 survey of the reintroduced sea otter population in Washington State*. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA.

Jeffries, S.J., P.J. Gearin, H.R. Huber, D.L. Saul, and D.A. Pruett. 2000. *Atlas of seal and sea lion haulout sites in Washington.* Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA.

Jeffries, S.J., H. Huber, J. Calambokidis, and J. Laake. 2003. Trends and status of harbor seals in Washington state: 1978-1999. *Journal of Wildlife Management* 67(1):207-218.

Jenkins, C., M. E. Haas, A. Olson, and J. L. Ruesink. 2002. Impacts of trampling on a rocky shoreline of San Juan Island, Washington. *Natural Areas Journal* 22:260-269.

Jessup, D.A., M.A. Miller, J.P. Ryan, H.M. Nevins, H.A. Kerkering, et al. 2009 Mass stranding of marine birds caused by a surfactant-producing red tide. *PLoS ONE* 4(2):e4550.

Johnson, D.H. and T.A. O'Neil (managing directors). 2001. *Wildlife-Habitat Relationships in Oregon and Washington*. Oregon State University Press, Corvallis, OR.

Kerr, R.A., E. Kintisch, L. Schenkman, and E. Skokstad. 2010. Gulf oil disaster: Five questions on the spill. *Science* 328(5981):962-963.

Kingsford, M.J. 1992. Drift algae and small fish in coatal waters of northeastern New Zealand. *Marine Ecology Progress Series* 80:41-55.

Kingsford, M.J. 1995. Drift algae: a contribution to near-shore habitat complexity in the pelagic environment and an attractant for fish. *Marine Ecology Progress Series* 116:297-301.

Laidre, K.L. and R.J. Jameson. 2006. Foraging patterns and prey selection in an increasing and expanding sea otter population. *Journal of Mammology* 87(4):799-807.

Laidre, K.L., R.J. Jameson, E. Gurarie, S.J. Jeffries, and H. Allen. 2009. Spatial habitat use patterns of sea otters in coastal Washington. *Journal of Mammology* 90(4):906-917.

Laidre, K.L., R.J. Jameson, S.J. Jeffries, R.C. Hobbs, C.E. Bowlby, and G.R. VanBlaricom. 2002. Estimates of carrying capacity for sea otters in Washington state. *Wildlife Society Bulletin*, 30(4):1172-1181.

Lafferty, K.D. 2001. Disturbance to wintering western snowy plovers. *Biological Conservation* 101(3):315-325.

Landry, M., J.R. Postel, W.K. Peterson, and J. Newman. 1989. Broad-scale distributional patterns of hydrographic variables on the Washington/Oregon Shelf. Pages 1-40 In: Landry, M. and B. Hickey (Eds.). *Coastal Oceanography of Washington and Oregon*. Elsevier Press, Amsterdam.

Lalli, C.M. and T.R. Parsons. 1993. *Biological oceanography: an introduction*. Oxford, New York.

Leigh, E.G., R.T. Paine, J.F. Quinn, and T.H. Suchanek. 1987. Wave energy and intertidal productivity. *Proceedings of the National Academy of Sciences* 84:1314-1318.

Lester, S.E., K.L. McLeod, H. Tallis, M. Ruckelshaus, B.S. Halpern, P.S. Levin, F.P. Chavez, C. Pomeroy, B.J. McCay, C. Costello, S.D. Gaines, A.J. Mace, J.A. Barth, D.L. Fluharty, and J.K. Parrish. 2010. Science in support of ecosystem-based management for the US West Coast and beyond. *Biological Conservation* 143:576-587.

Levin, P.S., M.J. Fogarty, S.A. Murawski, and D. Fluharty. 2009. Integrated ecosystem assessments: Developing the scientific basis for ecosystem-based management of the ocean. *PLoS Biology* 7(1):e1000014.

Levin, S.A. and J. Lubchenco. 2008. Resilience, robustness, and marine ecosystem-based management. *BioScience* 58(1):27-32.

Lewin, J., C.T. Schaefer and D.F. Winter. 1989. Surf-zone ecology and dynamics. In M.R. Landry and B.M. Hickey (Eds.), *Coastal Oceanography of Washington and Oregon*. Elsevier, Amsterdam.

Lewis, J.R. 1964. *The Ecology of Rocky Shores*. England University Press, London.

Li, H. and M.C. Boufadel. 2010. Long-term persistence of oil from the Exxon Valdez spill in two-layer beaches. *Nature Geoscience* 3:96-99.

Lyver, P.O., H. Moller, and C. Thompson. 1999. Changes in sooty Shearwater Puffinus griseus chick production and harvest procede ENSO events. *Marine Ecology Progress Series* 188:237-248.

Marsh, C.P. 1986 Rocky intertidal community organization: the impact of avian predators on mussel recruitment. *Ecology* 67(3) 771-786.

Massey, J.G., S. Hampton, and M. Ziccardi. 2005. A cost/benefit analysis of oiled wildlife response. 2005 International Oil Spill Conference.

Matkin, C.O, E.L. Saulifis, G.M. Ellis, P. Olesiuk, and S.D. Rice. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the 'Exxon Valdez' oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series* 356:269-281.

McDonald, P.S., G.C. Jensen, L. Carr, B.R. Dumbauld, and D.A. Armstrong, 2001. Possible Biological Constraints on Spatial Distribution and Abundance of the Nonindigenous Green Crab *Carcinus maenas* (L.) on the West Coast of North America, University of Washington. In: *Proceedings of the Second International Conference on Marine Bioinvasions*, pp. 96-97. New Orleans, LA, April 9-11, 2001.

Melvin, E.F., J.K. Parrish, and L.L. Conquest. 1999. Novel tools to reduce seabird bycatch in coastal gillnet fisheries. *Conservation Biology* 13(6):1386-1397.

Miller, C.B. 2004. *Biological Oceanography*. Blackwell, Oxford.

Miller, G.H. 1997. *Eelgrass distribution, density, leaf lengh and standing stock in Grays Harbor, 1977*. Prepared for Seattle District, Army Corps of Engineers under contract #DACW67-77-M-1240. Washington Department of Game, Olympia, WA.

Mills, K. L., W.J. Sydeman, and P.J. Hodum (Eds.), 2005. *The California Current Marine Bird Conservation Plan, v. 1*, PRBO Conservation Science, Stinson Beach, CA.

Momot, J.J. 1995. *Nestucca Oil Spill Restoration Plan*. U.S. Fish and Wildlife Service, Western Washington Office, Olympia, WA.

Mumford, T.F. 2007. *Kelp and eelgrass in Puget Sound*. Puget Sound Nearshore Partnershis Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, WA.

Murray, S.N., R.F. Ambrose, and M.N. Dethier. 2006. *Monitoring Rocky Shores*. University of California Press, Berkely, CA.

National Centers for Coastal Ocean Science. 2009. Massive Seabird Mortality Event in Oregon Linked to Harmful Algal Bloom - NCCOS and Partners Respond. Retrieved 20 September 2010 from http://www.cop.noaa.gov/stressors/extremeevents/hab/features/seabirds_hab.aspx

National Research Council. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water*. Committee on Ships' Ballast Operations, National Research Council. National Academy Press, Washington, D.C.

Nearshore Habitat Program. 2001. *The Washington State ShoreZone Inventory*. Washington State Department of Natural Resources, Olympia, WA.

National Oceanic and Atmospheric Administration. 2008. Shoreline Sensitivity Rankings List. Retrieved 18 May 2010 from http://response.restoration.noaa.gov/topic_subtopic_entry.php?RECORD_KEY%28entry_subtopic_topic%29=entry_id,subtopic_id,topic_id&entry_id(entry_subtopic_topic)=692&subtopic_id(entry_subtopic_topic)=8&topic_id(entry_subtopic_topic)=1

National Oceanic and Atmospheric Administration. 2010. Taking and Importing Marine Mammals; Navy Training Activities Conducted Within the Northwest Training Range Comples. Final rule. 50 CFR Part 218.

Northwest Area Committee. 2010. *Northwest Area Contingency Plan*. Retrieved 30 November 2010 from http://www.rrt10nwac.com/nwacp/

O'Connell, K.A. 2002. *Effects of invasive Atlantic smooth-cordgrass (*Spartina alterniflora*) on infaunal macroinvertebrate communities in southern Willapa Bay, WA*. MS thesis, Western Washington University.

Office of National Marine Sanctuaries. 2008. *Olympic Coast National Marine Sanctuary Condition Report 2008*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD.

Olympic Coast National Marine Sanctuary. 2011. *Draft Management Plan and Draft Environmental Assessment*. Retrieved 04 April 2011 from http://olympiccoast.noaa.gov/protection/mpr/mpr_draftdoc.html.

Overland, J., S. Rodionov, S. Minobe, N. Bond. 2008. North Pacific regime shifts: Definitions, issues and recent transitions. *Progress in Oceanography* 77:92-102.

Paine, R.T., J.L. Ruesink, A. Sun, E.L. Soulanillem, M.J. Wonham, C.D.G. Harley, C.R. Brumbaugh and D.L. Secord. 1996. Trouble on oiled waters: lessons from the "Exxon Valdez" oil spill. *Annual Review of Ecology and Systematics* 27:197-235.

Palumbi, S.R., K.L. McLeod, and D. Grünbaum. 2008. Ecosystems in action: Lessons from Marine Ecology about recovery, resistance, and reversibility. *BioScience* 58(1):1-33.

Partridge, V. 2007. *Condition of Coastal Waters of Washington State, 2000-2003: A Statistical Summary*. Washington State Department of Ecology, Olympia, WA. Publication 07-03-051. Retrieved 20 September 2010 from http://www.ecy.wa.gov/biblio/0703051.html

Pearson, S.F., M.G. Raphael, M.M. Lance, and T. D. Bloxton, Jr. 2010. *Washington 2009 at-sea marbled murrelet population monitoring: Research Progress Report*. Washington Department of Fish and Wildlife, Wildlife Science Division and USDA Forest Service Pacific Northwest Research Station, Olympia, WA.

Pearson, S.F., C. Sundstrom, and K. Gunther, D. Jaques, and K. Brennan. 2008. *Snowy Plover Population Monitoring, Research, and Management Actions: 2008 Nesting Season Research Progress Report*. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Pearson, S.F., C. Sundstrom, W. Ritchie, and K. Gunther. 2009. *Washington State Snowy Plover Population Monitoring, Research, and Management: 2009 Nesting Season Research Progress Report*. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Perry, A.L., P.J. Low, F.R. Ellis, J.D. Reynolds. 2005. Climate change and distribution shifts in marine fishes. *Science* 308:1912-1915.

Peterson, B.J. and K.L. Heck, Jr. 2001. Positive interactions between suspension-feeding bivalves and seagrass – a facultative mutualism. *Marine Ecology Progress Series* 213:143-155.

Peterson, C.H, S.D. Rice, J.W. Short, D. Esler, J.L. Bodkin, B.E. Ballachey, D.B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. *Science* 302:2082-2086.

Pew Oceans Commission. 2003. *America's Living Oceans: Charting a Course for Sea Change: A Report to the Nation*. Pew Oceans Commission, Arlington, Virginia.

Pirhalla D.E., V. Ransibrahmanakul, R. Clark, A. Desch, T. Wynne, and M. Edwards. 2009. *An Oceanographic Characterization of the Olympic Coast National Marine Sanctuary and Pacific Northwest: Interpretive Summary of Ocean Climate and Regional Processes Through Satellite Remote Sensing*. NOAA Technical Memorandum NOS NCCOS 90. Prepared by NCCOS's Coastal Oceanographic Assessments, Status and Trends Division in cooperation with the National Marine Sanctuary Program. Silver Spring, MD.

Pitcher, K.W., Olesiuk, P.F., Brown, R.F., Lowry, M.S., Jeffries, S.J., Sease, J.L., Perryman, W.L., Stinchcomb, C.E., and Lowry, L.F. 2007. Abundance and distribution of the eastern North Pacific Steller sea lion (*Eumetopias jubatus*) population. *Fisheries Bulletin* 107:102–115.

Puget Sound Partnership. 2010. *Strategic Science Plan*. January 2010 Review Draft. Prepared by the Puget Sound Partnership Science Panel. Puget Sound Partnership. Olympia, Washington.

Raphael, Martin G.; Baldwin, Jim; Falxa, Gary A.; Huff, Mark H.; Lance, Monique; Miller, Sherri L.; Pearson, Scott F.; Ralph, C. John; Strong, Craig; Thompson, Chris. 2007. *Regional population monitoring of the marbled murrelet: field and analytical methods*. Gen. Tech. Rep. PNW-GTR-716. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Ray, G.C. and J. McCormick-Ray. 2004. *Coastal-marine conservation: science and policy*. Malden, MA, Blackwell Publishing.

Risien, J. (Ed.). 2009. *West Coast Regional Marine Research and Information Needs*. Oregon Sea Grant ORESU-Q-09-001. Corvallis, Oregon.

Roegner, G.C., B.M. Hickey, J.A. Newton, A.L Shanks, and D.A. Armstrong. 2002. Wind-induced plume and bloom intrusions into Willapa Bay, Washington. *Limnology and Oceanography* 47(4):1033-1042.

Rolland, V., C. Barbraud, H. Weimerskirch. 2008. Combined effects of fisheries and climate on a migratory long-lived marine predator. *Journal of Applied Ecology* 45(1):4-13.

Ruckelshaus, M., T. Klinger, N. Knowlton, D.P. DeMaster. 2008. Marine ecosystem-based management in practice: Scientific and governance challenges. *BioScience* 58(1):53-63.

Ruesink, J.L., H.S. Lenihan, A.C. Trimble, K.W. Heiman, F. Micheli, J.E. Byers, and M. Kay. 2005. Introduction of non-native oysters: ecosystem effects and restoration implications. *Annual Review of Ecology, Evolution and Systematics* 36:643-689.

Ruesink J.L., B.E. Feist, C.J. Harvey, J.S. Hong, A.C. Trimble, and L.M. Wisehart. 2006. Changes in productivity associated with four introduced species: ecosystem transformation of a 'pristine' estuary. *Marine Ecology Progress Series* 311:203-215.

Ruesink, J.L., J.-S. Hong, L. Wisehart, S.D. Hacker, B.R. Dumbauld, M. Hessing-Lewis, and A.C. Trimble. 2009. Congener comparision of native (*Zostera marina*) and introduced (*Z. japonica*) eelgrass at multiple scales within a Pacific Northwest estuary. Biological Invasions (12):1773-1789.

Searing, G.F. and H.R. Frith. 1995. *British Columbia biological shore-zone mapping system*. Contract Report by LGL Ltd., Sidney, BC for Land-Use Coordination Office, BC Ministry of Environment, Victoria, BC.

Shaffer, J.A. 2001. Nearshore marine habitats of Clallam County. In: *Proceedings, Clallam County MRC workshop series.* Clallam County, Washington.

Shaffer, J.A., D.C. Doty, R.M. Buckley and J.E. West. 1995. Crustacean community composition and trophic use of the drift vegetation habitat by juvenile splitnose rockfish, Sebastes diploproa. *Marine Ecology Progress Series* 123:13-21.

Shanks, A.L., B. Grantham, and M.H. Carr. 2003. Propagule dispersal distance and the size and spacing of marine reserves. *Ecological Applications* 13:S159-S169.

Sherman K. 1995. Achieving regional cooperation in the management of marine ecosystems: The use of the large marine ecosystem approach. *Ocean and Coastal Management* 29:165-185.

Short, J.W., G.V. Irvine, D.H. Mann, J.M. Maselko, J.J. Pella, M.R. Lindeberg, J.R. Payne, W.B. Driskell and S.D. Rice. 2007. Slightly weathered Exxon Valdez oil persists in Gulf of Alaska beach sediments after 16 years. *Environmental Science and Technology* 41(4):1245-1250.

Simenstad, C.A. and K.L. Fresh. 1995. Influence of intertidal aquaculture on benthic communities in Pacific Northwest estuaries: Scales of disturbance. *Estuaries* 18(1):43-70.

Simenstad, C., L.F. Small, C.D. McIntire, D.A. Jay and C. Sherwood. 1990. Columbia River estuarine studies: an introduction to the estuary, a brief history, and prior studies. *Progress in Oceanography* 25:1-14.

Southwest Washington Coastal Erosion Study. 2008. Retreived 19 August 2010 from http://www.ecy.wa.gov/programs/sea/swces/index.htm

Speich, S.M. and T.R. Wahl. 1989. *Catalog of Washington seabird colonies*. U.S. Fish and Wildlife Service Biological Report 88(6).

Strickland, R. (Ed.). 1996. *Olympic Coast Marine Research: Proceedings of a workshop held at the Olympic Natural Resources Center*. Occasional Paper OCNMS 96-01. Sponsored by Olympic Coast National Marine Sanctuary, Port Angeles, WA.

Strickland, R. and D.J. Chasan. 1989. Coastal Washington: A synthesis of information. Washington State & Offshore Oil and Gas. Washington Sea Grant Program, University of Washington, Seattle, WA.

Swanson, T., D. Canning, S. O'Shea, B. Shorin, and T. Trihimovich (Eds.). 2001. Managing Washington's Coast – Washington State's Coastal Zone Management Program. Publication 00-06-029. Washington Department of Ecology, Olympia, WA.

Tallis, H., P.S. Levin, M. Ruckelshaus, S.E. Lester, K.L. McLeod, D.L. Fluharty, B.S. Halpern. 2010. The many faces of ecosystem-based management: Making the process work to day in real places. *Marine Policy* 34:340-348.

Tallis, H.M., J.L. Ruesink, B. Dumbauld, S. Hacker, and L.M. Wisehard. 2009. Oysters and aquaculture practices affect eelgrass density and productivity in a Pacific Northwest estuary. *Journal of Shellfish Research* 28(2):251-261.

Teal, J.M., J.W. Farrington, K.A. Burns, J.J. Stegeman, B.W. Tripp, B. Woodin and C. Phinney. 1992. The West Falmouth oil spill after 20 years: fate of fuel oil compounds and effects on animals. *Marine Pollution Bulletin* 24:607-614.

Tenyo Maru Trustees. 1993. *Tenyo Maru* Oil Spill Habitat Impacts, Resource Injuries, Damage Claims and Restoration Summaries. Lacey, WA.

The *Tenyo Maru* Oil Spill Natural Resource Trustees. 2000. Final Restoration Plan and Environmental Asessment for the Tenyo Maru Oil Spill. Makah Indian Tribe, State of Washington, U.S. Department of Commerce, and U.S. Department of the Interior.

Thom, R.M. and A.B. Borde. 1998. Human intervention in Pacific Northwest coastal ecosystems. Chapter 2, pp. 5-37 in G.R. McMurray and R.J. Bailey, editors. *Change in Pacific Northwest Coastal ecosystems,* Decision Analysis Series No. 11. NOAA Coastal ocean program.

Thom, R.M., A.B. Borde, S.L. Blanton, D.L. Woodruff, and G.D. Williams. 2001. The influence of climate variation and change on structure and processes in nearshore vegetated communities of Puget Soun and other northwest estuaries. *2001 Puget Sound Research Proceedings*. Pacific Northwest National Laboratory, Marine Sciences Laboratory.

Thom, R.M, A.B. Borde, S. Runrill, D.L. Woodruff, G.D. Williams, J.A. Southard, and S.L. Sargeant. 2003. Factors influencing spatial and annual variability in Eelgrass (*Zostera marina* L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, Estuaries. *Estuaries* 26(4B):1117-1129.

Trainer, V. M. and M. Suddleson. 2005. Monitoring approaches for early warning of domoic acid events in Washington State. *Oceanography* 18 (2):228-237.

Trainer, V.L, B.M. Hickey, E.J. Lessard, W.P. Cochlan, C.G. Trick, M.L. Wells, A. MacFadyen, and S.K. Moore. 2009. Variability of Pseudo-nitzschia and domoic acid in the Juan de Fuca eddy region and its adjacent shelves. *Limnology and Oceanography* 54(1):289-308.

Trimble A.C., J.L. Ruesink, and B.R. Dumbauld. 2009. Factors preventing the recovery of a historically overexploited shellfish species, *Ostrea lurida Carpenter 1864*. *Journal of Shellfish Research* 28(1):97-106.

U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century*. Washington, D.C.

U.S. Fish and Wildlife Service. 2004. Final *Nestucca* Oil Spill Revised Restoration Plan. Western Washington Fish and Wildlife Office, Lacey, Washington.

U.S. Fish and Wildlife Service. 2005. *Regional seabird conservation plan, Pacific Region*. U.S. Fish and Wildlife Service, Migratory Birds and Habitat Programs, Pacific Region, Portland, Oregon. Retrieved from http://www.fws.gov/pacific/migratorybirds/Seabird_Conservation_Plan_pdf.htm

U.S. House Hearing. 2003. Harmful algal blooms and hypoxia: strengthening the science. Hearing before the Subcommittee on Environment, Technology, and Standards of the Committee on Science, House of Representatives, One Hundred Eighth Congress, first session, March 13, 2003.

U.S. House Hearing. 2009. Harmful algal blooms and hypoxia: formulating an action plan. Hearing before the Subcommittee on Energy and Environment of the Committee on Science, House of Representatives, One Hundred Eleventh Congress, first session, September 17, 2009.

Van Cleve, F.B., G. Bargmann, M. Culver, and the MPA Work Group. 2009. *Marine Protected Areas in Washington: Recommendations of the Marine Protected Areas Work Group to the Washington State Legislature*. Washington Department of Fish and Wildlife, Olympia, WA.

Veit, R.R., J.A. Mcgowan, D.G Ainley, T.R. Wahls, and P. Pyle. 1997. Apex marine predator declines ninety percent in association with changing oceanic climate. *Global Change Biology* 3(1):23-28.

Waaland, J.R. 1977. *Common Seaweeds of the Pacific Coast*. Pacific Search Press, Seattle, WA.

Washington Department of Ecology. 1992. *Washington State Coastal Sensitive Areas Mapping Project*. Prepared for the Washington State Department of Ecology by the Department of Landscape Architecture, University of Washington, Seattle, WA.

Washington Department of Fish and Wildlife. 2010. Aquatic Invasive Species. Retrieved 19 August 2010 from http://wdfw.wa.gov/ais/

Washington Department of Natural Resources. 2007. *State of Washington Natural Heritage Plan 2007*. Olympia, WA.

Washington Department of Natural Resources. 2008. *Chehalis River Surge Plain Natural Area Preserve Management Plan* (draft). Prepared by Pacific Cascade Region Natural Areas Program. Retrieved 12 October 2010 from http://www.dnr.wa.gov/Publications/amp_nap_chehalis_river_surge_plain_draft.pdf

Washington State Department of Agriculture . 2007. Spartina *Eradication Program 2007 Progress Report*. Retrieved 19 August 2010 from http://agr.wa.gov/PlantsInsects/Weeds/Spartina

Washington State Department of Agriculture. 2010. State Department of Agriculture begins *Spartin*a treatments for 2010 season. Retrieved 19 August 2010 from http://agr.wa.gov/News/2010/10-14.aspx

Washington State Ocean Policy Work Group. 2006. *Washington's Ocean Action Plan: Enhancing Management of Washington State's Ocean and Outer Coasts*. Olympia, WA.

West Coast Governors' Agreement on Ocean Health. 2008. *Action Plan*. The Office of the Governors: Washington, Oregon, and California. Retrieved from http://www.westcoastoceans.gov

Whitmire, C.E. and M.E. Clarke. 2007. State of U.S. deep coral ecosystems in the United States Pacific coast: California to Washington. pp. 109-154. In: SE Lumsden, Hourigan TF, Bruckner AW and Dorr G (Eds.). *The State of Deep Coral Ecosystems of the United States*. NOAA Technical Memorandum CRCP-3. Silver Spring MD.

Williams, S.L. and K.L. Heck, Jr. 2001. Seagrass community ecology. In: M.D. Bertness, S.D. Gaines, and M.E. Hay (Eds.). *Marine Community Ecology*. Sinauer Associates, Sunderland MA.

Wilson, U.W. 1991. Responses of 3 seabird species to El Niño events and other warm episodes on the Washington coast, 1979-1990. *Condor* 93(4):853-858.

Wilson, S. and V. Partridge, 2007. *Condition of Outer Coastal Estuaries of Washington State, 1999: A Statistical Summary*. Washington State Department of Ecology, Olympia, WA. Publication 07-03-012. Retrieved 20 September 2010 from http://www.ecy.wa.gov/biblio/0703012.html

Wolfe, D.A., M.M. Krahn, E.Casillas, S. Sol, T.A. Thompson, J. Lunz, and K.J. Scott. 1996. Toxicity of intertidal and subtidal sediments contaminated by the Exxon Valdez oil spill. *American Fisheries Society Symposium* 18:121-139.

Wonham, M.J. 2001. *Ecology and management of marine biological invasions: distribution and environmental constraints in Mytilus galloprovincialis*. PhD Dissertation, University of Washington.

Wootton, J.T. 1997. Estimates and tests of per capita interaction strength: diet, abundance, and impact of intertidally foraging birds. *Ecological Monographs*, 67(1):45-64.

Youngmann, C. (1977-1980). *Coastal zone atlas of Washington*. Washington Department of Ecology. Olympia, WA.