Preliminary Draft Marine Spatial Plan

An interagency team of state agencies, including Washington departments of Ecology, Natural Resources and Fish and Wildlife, developed the preliminary draft Marine Spatial Plan with input from local, federal and tribal governments, and stakeholders including the Washington Coastal Marine Advisory Council.

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Marine Spatial Plan for Washington's Pacific Coast

A Marine Spatial Plan (MSP) is currently under development for Washington's Pacific Ocean coast. The MSP provides:

- Guidance for new ocean uses along Washington's Pacific coast, such as renewable energy projects and offshore aquaculture.
- Baseline data on coastal uses and resources to capture current conditions and future trends.
- Requirements and recommendations for evaluating new ocean uses through the different phases of project review consistent with existing laws and regulations.
- Recommendations to protect important and sensitive ecological areas and existing uses like fishing.

Preliminary Review

A preliminary draft is now available for review by key stakeholders and tribes. A more formal draft plan is targeted for release for public comment in May 2017. While not required, a preliminary draft:

- Assists state agencies by getting early input from groups that have been engaged in the process for several years.
- Helps better prepare the draft plan for public comment by refining how plans and regulations fit together, identifying missing information and addressing concerns about recommendations.
- Enables the state meet a target for completing the MSP by June 2017.

Please see instructions for commenting on the preliminary draft MSP in the box at left.

Marine Spatial Plan for Washington's Pacific Coast

Section 2: Current Conditions and Future Trends

2.1 Ecology of Washington's Pacific Coast

Washington's Marine Spatial Plan (MSP) Study Area[1] is a highly productive, diverse ecosystem. Living resources within this ecosystem are the foundation to Washington's ocean uses. The health and status of the Study Area's species, habitats, and ecosystem are of primary importance to ocean and estuarine users, coastal residents, tribes, and the state of Washington. The Study Area has several federally and state designated protected areas (Map 1) designed to protect and foster the health of important habitats and species off Washington's Pacific coast.

This chapter describes the ecology of the MSP Study Area by summarizing the physical oceanography, water quality status, geomorphology, biology, and ecological stressors of Washington's outer coast. Information presented here can be used to understand not only the ecological context of Washington's ocean and estuaries, but also for considering potential future new uses and how they may affect the ecological status of the Study Area. While climate change is mentioned briefly in this section, a more detailed and thorough explanation of the impacts of climate change on the ecology of the MSP Study Area can be found in Section 2.11: Climate Change.

Physical Oceanography

Washington's coast is influenced by local and regional climate as well as large-scale oceanic forces. The currents, tides, eddies, plumes, temperature, and other physical features of the Washington coast shape habitat, fisheries, and other important services provided by these highly productive waters. The following section discusses the main physical oceanographic features that influence the MSP Study Area.

Currents, Upwelling, and Productivity

The Pacific Northwest (including the outer Pacific coast of Washington) is predominantly influenced by large-scale ocean processes that exhibit seasonal patterns and a highly dynamic ocean environment (Hickey & Banas, 2003). The dominant oceanographic feature of the Pacific Northwest (PNW) is the California Current System (CCS), which has strong interannual, seasonal, and daily variability. The CCS includes the strong southward flowing California Current, which flows year-round offshore from the shelf break, and a California Undercurrent which flows northward along the continental slope. The CCS also includes the northward flowing Davidson Current in the winter and the southward flowing California Coastal Jet Current in the summer. Each current has distinct properties (e.g., temperature, nutrients, oxygen, salinity, etc.) depending upon the source waters, including the Pacific Subarctic, North Pacific Central, and Southern water masses (Hickey & Banas, 2003; Pirhalla et al., 2009).

Seasonal circulation patterns bring the water properties from these currents into the region and strongly influence productivity, transportation routes for larval fish and shellfish, plankton, and other important ecological features (Hickey & Banas, 2003, 2008; Pirhalla et al., 2009). The PNW has an upwelling/downwelling seasonal pattern driven by offshore wind. Upwelling occurs mostly during spring and summer when the wind comes from the north, but with important 'conditioning' events occurring in the winter (Black et al., 2011). Upwelling is the process by which currents and southward wind stress, combine with the Coriolis force to push surface water offshore and replace it with deep, cold, salty, nutrient-rich water from below (Figure 2.1-1). Upwelling brings nutrients up into the photic zone (the upper portion of the water column where sunlight penetrates) where nutrients are then available to phytoplankton that form the base of the coastal and ocean food web. Upwelling can be variable on a several day scale, with periods of strong upwelling and periods of relaxed wind and reduced upwelling

[1] The MSP Study Area is defined in Section 1.5.

during the spring and summer seasons (Andrews, Harvey, & Levin, 2013; Hickey & Banas, 2003, 2008; Pirhalla et al., 2009).

The seasonal pattern generally transitions to downwelling during the fall that persists throughout winter. During downwelling, currents and northward wind stress push water onshore, and this water is typically warmer, less saline, and has fewer nutrients (Hickey & Banas, 2003). Seasonal upwelling and downwelling events are generally well characterized within the literature, and these events can be detected by analyzing parameters such as sea surface height and chlorophyll-a (Pirhalla et al., 2009). Figure 2.1-2 provides a general example of seasonal chlorophyll measurements along Washington's coast corresponding to increases in chlorophyll in spring and summer (upwelling) and decreases in fall and winter (downwelling).

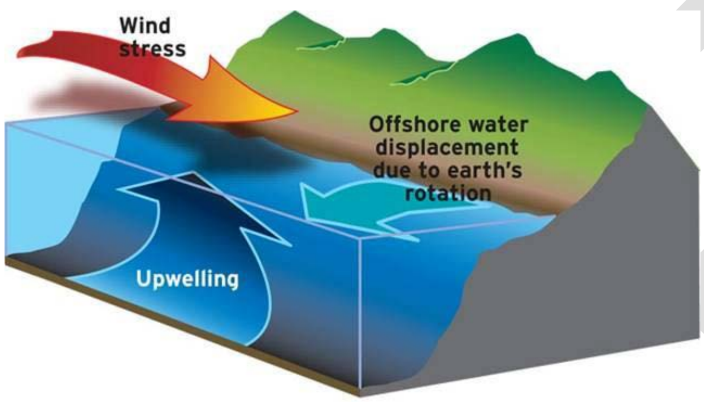


Figure 2.1-1. Schematic of upwelling forces. Source: Northwest Fisheries Science Center as provided in the IEA.

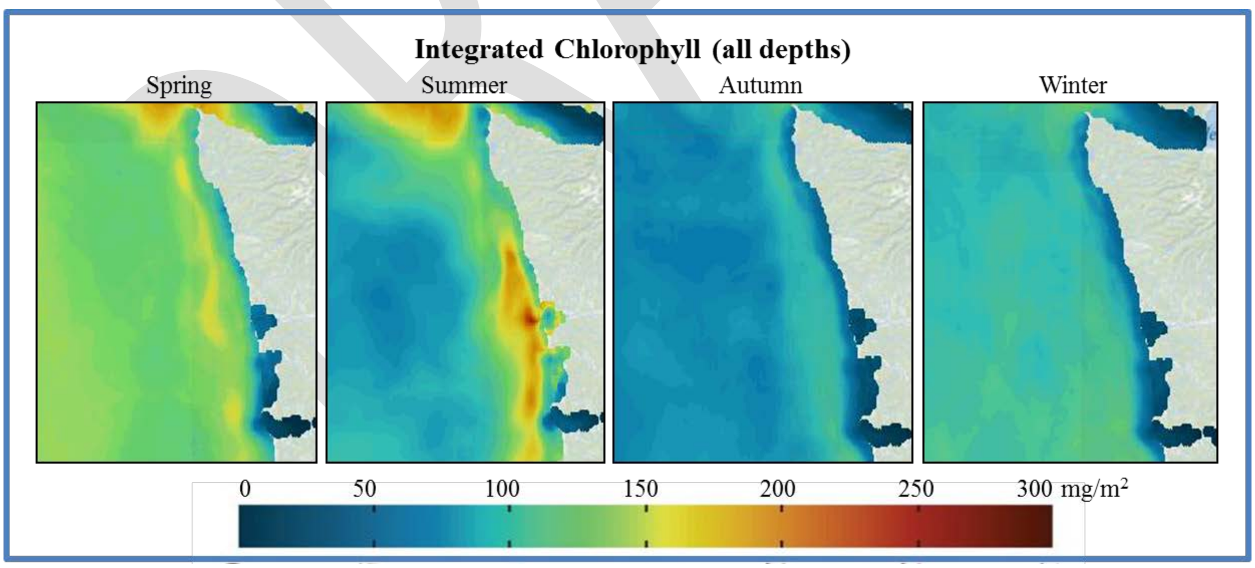


Figure 2.1-2. Integrated chlorophyll (all depths) for 2005-2006. Source: Ocean conditions page.

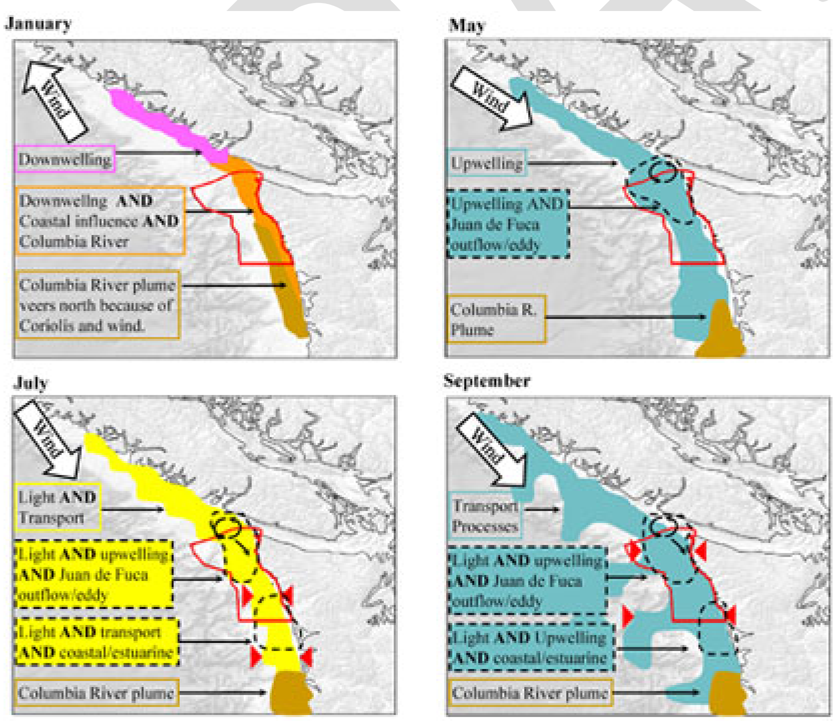
In addition to upwelling, other features influence ocean and coastal productivity along the Washington coast. A significant aspect is the Juan de Fuca Eddy, a semi-permanent feature located off the coasts of northern Washington and southern Vancouver Island of British Columbia. The Eddy forms in the spring, dissipates in the fall, and is formed by the outflow from the Salish Sea through the Strait of

Juan de Fuca. The Eddy is characterized by high nutrients, increased productivity and retention, and enhanced higher trophic-level biomass (Andrews et al., 2013; Hickey & Banas, 2008).

The Columbia River Plume is another major feature that influences productivity along the Washington coast. The river plume brings freshwater, sediment, nutrients, carbon, and organic matter which increase primary productivity in marine waters. The plume also influences water circulation, retention, and transportation which effect plankton and larval fish. The Columbia River Plume can vary in orientation, but is generally pushed northward along the coast in the winter during downwelling and generally southwestward during the summer, although this may vary during weak upwelling periods (Andrews et al., 2013; Burla, Baptista, Zhang, & Frolov, 2010; Hickey & Banas, 2008). While the Columbia River Plume generally provides fewer nutrients to the ocean during the summer months, Hickey and Banas (2008) suggest the plume may help sustain local ecosystems by providing a nutrient supply during periods of weak to no upwelling or during late spring transitions.

Coastal trapped waves, a complex interaction of shelf slope, wind, and angular momentum, are another important physical process feature and can accelerate local alongshore currents. Coastal trapped waves can generate as far south as central California (Hickey & Banas, 2003). Features such as the Juan de Fuca Eddy, the Columbia River Plume, coastal trapped waves, and submarine canyons (described below) are estimated to contribute significantly to the higher productivity of the Washington coast as compared to the rest of the PNW (southern Oregon and northern California) (Hickey & Banas, 2008). An illustration of the major physical factors influencing seasonal nutrient availability in Washington waters is provided in Figure 2.1-3.

Figure 2.1-3. Schematic of general physical factors limiting nutrient availability and surface response during January, May, July, and September. Source: (Pirhalla et al., 2009).



Estuaries

Several estuaries occur within the MSP Study Area. Estuaries in the northern portion of the Study Area are relatively small outlets from coastal rivers. Two large estuaries in the southern portion of the Study Area, Grays Harbor and Willapa Bay, are significant features of the southern coast. Grays Harbor and Willapa Bay consist of multiple channels surrounded by wide, shallow mudflats. Over half of the surface area in each of these two estuaries is intertidal (Hickey & Banas, 2003). Rivers emptying into Grays Harbor and Willapa Bay are dominated by local rainfall. This leads to higher river flow in the winter, intermittent flows in the spring, and low flows in the summer. The large estuaries within the MSP Study Area are highly influenced by oceanographic forces, including the upwelling/downwelling cycle (Hickey & Banas, 2003).

Tides

Tidal patterns contribute to the high biological diversity of intertidal habitats along the Washington coast. Tides in Washington are mixed semidiurnal, meaning that there are typically two high tides and two low tides per day and the consecutive highs and lows differ in height. The daily tidal range is 2 to 4 meters (6.5 to 13 feet) (Ruggiero et al., 2013). In Grays Harbor and Willapa Bay, oceanic waters flush up to half of the water volume twice a day. In the spring and summer, very low tides occur in the morning, when cool temperatures and fog keep the physical stresses (high temperature, desiccation, etc.) on the tidal flats low. Low tides in the winter can cause freezing and mortality of exposed organisms (Hickey & Banas, 2003; Skewgar & Pearson, 2011). Tides contribute to the exchange of water, oxygen, nutrients, heat, and other physical conditions in the estuaries and beaches. This is critical for various organisms occupying different tidal zones, mudflats, rocky shores, and other communities (Andrews et al., 2013).

Climate and Large Scale Influences

Washington has a temperate climate, with high seasonal precipitation mostly from October to March, and dry, warmer conditions during the summer months. This seasonal rainfall and snowfall influences river flows, coastal turbidity and sediment input, temperature, and salinity gradients along the coast and in estuaries. Storms during the winter months also play an important role in shaping the physical environment (Hickey & Banas, 2003; Pirhalla et al., 2009; Skewgar & Pearson, 2011).

Large-scale, global processes influence climate from year to year and on an interdecadal scale. These large-scale climatic processes interact in complex ways with significant influence on ocean productivity. The El Niño-Southern Oscillation (ENSO) pattern causes system-wide differences in sea surface temperature, sea surface height anomalies, turbidity, and sediment transport processes (Pirhalla et al., 2009; Ruggiero et al., 2013; Skewgar & Pearson, 2011). For example, within the MSP Study Area, sea surface temperatures are generally warmer during the warm phase (El Niño) and cooler during the cool phase (La Niña) (Pirhalla et al., 2009). Also, during an El Niño phase, storms, large waves heights, and wave angles have been documented to create erosion hotspots in the PNW (Ruggiero et al., 2013). The Pacific Decadal Oscillation (PDO) also influences sea surface temperature and height (Pirhalla et al., 2009) over a longer timescale than ENSO. Another process, the North Pacific Mode (a.k.a. the Blob), has recently resulted in exceptionally warmer waters off the West Coast in 2013-2015 (Kintisch, 2015), and may have influenced marine species ranges and ocean productivity (Bond, Cronin, Freeland, & Mantua, 2015; Hartmann, 2015; Kintisch, 2015).

Storms and wave energy

The PNW is known for its severe wave climate, particularly during winter storms. Winter storms create deep-water significant wave heights greater than 10 meters (33 feet) and have generated wave heights up to 15 meters (49 feet). The strongest storms can achieve hurricane wind speeds. High, long-period waves with a west southwest approach characterize the winter months (November through February) and small waves (1 meter or 3 feet) from the west northwest are typical of calmer, summer conditions (May through August) (Ruggiero et al., 2013). Increasing wave heights and intensity of storms have been observed in the PNW over the last half of the 20th century (Ruggiero et al., 2013). Also, the frequency of strong storms has increased, while the frequency of weak to medium strength storms has decreased (Ruggiero et al., 2013). The storm and wave energy of the PNW has a significant influence on the physical conditions of the ocean and coast. Wave and storm energy influences erosion and accretion, sediment transportation, surf zone energy, and flooding.

Water quality

Water quality is important for species, habitats, and human health. Several water quality parameters are regularly monitored to study the causes, trends, and impacts of water quality. This information is used to develop and adapt management plans to address ecological and public health issues, such as pollution, toxins, and other impacts.

For some water quality parameters, the Washington State Department of Ecology (Ecology) has developed enforceable water quality standards to protect beneficial uses including human contact and aquatic life uses (e.g. salmonid migration, rearing, and spawning). The state is also required to use these standards to prepare a list of water quality limited segments under the Clean Water Act and EPA's implementing regulations. The Washington State Department of Health (WDOH) regulates shellfish harvesting under the National Shellfish Sanitation Program. This program designates commercial and recreational shellfish harvest areas and establishes fecal coliform bacteria limits to protect those uses. Water bodies are regularly monitored to evaluate whether or not these standards are met.

For Ecology's water quality assessment, all available and credible water quality and fish tissue data[2] are assessed and waterbody segments are evaluated and categorized into a water quality rating system based on the results (Washington State Department of Ecology, 2012b). Water quality assessment categories are as follows:

- Category 1: meets tested standards for water quality
- Category 2: waters of concern where there is some evidence of a water quality problem, but not enough to require production of a water quality improvement project at this time
- Category 3: insufficient data
- Category 4: polluted waters that do not require a TMDL
    - Category 4a: polluted waters with an approved total maximum daily load (TMDL)
    - Category 4b: polluted waters with an approved water quality improvement plan that is equivalent to a TMDL
    - Category 4c: is impaired by a non-pollutant
- Category 5: polluted waters that require a TMDL or another type of water quality improvement project

Category 5 listings are commonly referred to as 303(d) listings for impaired waters, in reference to section 303(d) of the federal Clean Water Act, and Ecology is required by EPA to develop and implement TMDLs for all category 5 listings.

[2] Data must meet the state Credible Data Quality Act.

TMDLs or other water quality improvement projects are a management approach to clean up 303(d) listed (polluted) waterbodies so that they meet state water quality standards. Water quality improvement plans allocate pollutant discharges to point and non-point sources so that the loading capacity (the maximum amount of pollutants a waterbody can receive and still meet water quality standards) is not exceeded. Wasteload allocations for point sources are incorporated into National Pollutant Discharge Elimination System (NPDES) permits that set effluent limits and requirements for treatment of their effluent. The implementation of best management practices (BMPs) is intended to reduce nonpoint pollution sources that affect water quality. The current water quality assessment was approved by the federal Environmental Protection Agency (EPA) in 2016.

Ecology also conducts water quality monitoring for parameters that are not included in the water quality standards to track changes in overall marine conditions due to human and climatic influences (Washington State Department of Ecology, 2014a, 2014b). Other priority water quality issues are monitored in Washington State by Ecology, other state agencies, and organizations. On tribal lands, the tribes, funded through the EPA and in some cases having established tribal water quality standards (e.g., Makah), monitor and regulate water quality[3]. The four coastal treaty tribes also monitor water quality in their respective U&As, using methods first approved by the EPA. The data are uploaded to the EPA STORET program. For the U&A, exceedances are determined using state water quality standards. The following are summaries of main water quality considerations within the MSP Study Area.

Dissolved Oxygen

Dissolved oxygen in the water is essential for all aerobic marine and estuarine life. Dissolved oxygen levels are primarily influenced by temperature, gas exchange with the atmosphere, and water source. Waters with high levels of respiration can become decreased in dissolved oxygen, either from an excess of nutrients producing decaying organic matter, or from deep ocean waters with a prolonged absence of photosynthesis. Colder water holds more dissolved oxygen, and warmer water holds less. Deep waters beyond the continental shelf naturally have low oxygen concentrations. Hypoxia (low dissolved oxygen concentrations) in Washington shelf and coastal waters is related to upwelling. Upwelling delivers oxygen-depleted water up from the bottom to the surface, periodically causing hypoxic or even anoxic (no oxygen) conditions. The layer of deep water along the upper continental slope extending to depths greater than 1,000 meters (3,280 feet) that has persistently low oxygen is called the oxygen minimum zone. Historical data suggests that this normally hypoxic layer is showing trends of increased temperature and even lower oxygen (Office of National Marine Sanctuaries, 2008).

Decreased oxygen levels in already low-oxygen deep waters or the intrusion of low-oxygen waters into shallower areas towards shore (via upwelling) can stress communities and kill marine organisms (Office of National Marine Sanctuaries, 2008). In 2006, hypoxic conditions were severe enough to cause widespread fish and invertebrate mortality along Washington and Oregon coasts (Chan et al., 2008; Office of National Marine Sanctuaries, 2008). Data indicate that the frequency, intensity, and extent of hypoxic conditions off of Oregon's shelf waters has been increasing since 2000, and anoxic conditions had never been recorded before 2006 (Chan et al., 2008).

In Willapa Bay, one water quality segment at the mouth of the Willapa River has been listed as Category 4a for dissolved oxygen, and other segments are listed as Category 2 towards the southern part of the bay near the mouth of the Naselle River and just west of Long Island (Washington State Department of Ecology, 2012a). The Willapa River Dissolved Oxygen TMDL study found that point sources were the primary negative influence on dissolved oxygen levels in the Willapa River. A TMDL

[3] The State does not address 303(d) listings on tribal lands but does for the tribal U&As off-reservation.

established wasteload allocations for wastewater treatment facilities and seafood processors that discharge to the Willapa River (Washington State Department of Ecology, 2006). Grays Harbor currently has no TMDLs for dissolved oxygen. Grays Harbor and Willapa Bay are strongly influenced by large oceanographic forces on the coast, and may experience low dissolved oxygen levels during upwelling events (C. Krembs, personal communication, May 7th, 2015).

Nutrients

Nutrients, like nitrogen and phosphorus, are essential to plant and animal nutrition, but in high concentrations can lead to a decline in water quality. Excess nutrients in water can lead to eutrophication, which can result in algae blooms, declines in submerged aquatic vegetation, depletion of dissolved oxygen, and mortality of fish and invertebrates. Nutrient concentrations can vary between location and systems, and are a result of complex natural and human-influenced sources. Anthropogenic sources of nutrients can come from point sources, such as sewage treatment plants and urban stormwater, or non-point sources such as failing septic systems and agricultural runoff (Andrews et al., 2013).

Nutrient concentrations can be naturally quite high along the Pacific Coast of Washington due to upwelling of nutrient-rich water and also from the Juan de Fuca outflow and Columbia River Plume, which drive the high productivity along the coast (Hickey & Banas, 2003). In general, human-caused increases in nutrients from point or nonpoint sources are not a concern for the northern coast of Washington since there are no significant population centers in the area (Office of National Marine Sanctuaries, 2008). Furthermore, determining the contributions of regional nutrient influences to the Pacific Coast from human sources is very difficult given the strong oceanographic influence through upwelled waters and high variability (C. Krembs, personal communication, May 7th, 2015).

Grays Harbor and Willapa Bay are strongly influenced by oceanographic forces such as currents and upwelling (Hickey & Banas, 2003), as well as riverine supply from the Chehalis River or Columbia River during downwelling winds from the south. Nutrient monitoring data from Ecology's Environmental Assessment Program show no significant trends in nutrient changes from 1999-2013 within Grays Harbor or Willapa Bay for nitrogen or phosphorus parameters (Washington State Department of Ecology, 2014a), and there are currently no TMDLs related to nutrients for either Grays Harbor or Willapa Bay (Washington State Department of Ecology, 2012a).

Carbon dioxide and ocean acidification[4]

Carbon dioxide (CO_2) dissolved in seawater decreases the pH of the water, making the ocean more acidified, resulting in a corrosive environment for some shell-forming organisms. The decline in pH is known as ocean acidification. CO_2 in the ocean can come from several sources. The primary driver of ocean acidification is from the ocean absorbing atmospheric CO_2, which is currently at significantly elevated levels compared to historic conditions from the burning of fossil fuels. On the Washington coast, low ocean pH is also a result of upwelled high-CO_2 ocean waters. Decomposition (respiration) of organic material releases CO_2, and these cold bottom waters, which have been out of contact with the ocean surface for up to a few decades, bring cold, CO_2-rich waters to the surface. This is a natural phenomenon. Other sources of ocean acidification include nutrients, which can increase algal blooms and in turn, increased decomposition of organic matter when the algae die, decreasing pH. Freshwater river inputs may also be more acidic than ocean water and therefore influence the acidity of estuarine and coastal waters (Feely, Klinger, Newton, & Chadsey, 2012).

[4] Ocean acidification is also discussed in Section 2.11: Climate Change.

When the oceans take up CO_2, the pH is lowered and the availability of carbonate (CO_3^{2-}) is also reduced. The reduced pH and carbonate availability lowers the saturation state of the calcium carbonate ($CaCO_3$) biominerals: aragonite and calcite, which are used in shell and exoskeleton formation of many marine species. When the saturation state is lowered, it can become more difficult for shell forming organisms, such as oysters, crabs, corals, pteropods, and phytoplankton, to build their shells necessary for survival. Ocean acidification has the potential to affect populations, species distributions, food webs, and disease prevalence (Feely et al., 2012).

The Washington coast is particularly vulnerable to ocean acidification because upwelling naturally brings low pH waters to the coast. Effects of low aragonite saturation states have already been observed in the oyster industry, where PNW oyster hatcheries were experiencing mass mortalities when raising oyster larvae in the mid-2000s. Natural oyster recruitment was also low during these years. CO_2 and saturation state monitoring revealed that the water intake during those failure events was low in pH and saturation state. The industry has utilized monitoring equipment and pH buffering to adapt to the acidic conditions and increase hatchery success (Feely et al., 2012). Pteropods are an important component of the marine food web in Washington as they are consumed by fish, seabirds, and whales, and are a key prey for salmon. Studies have shown that pteropod species suffer decreases in calcification and growth rates with declining pH (Feely et al., 2012).

Scientists anticipate that ocean acidification conditions and effects will increase in the future, causing more challenges for the oyster industry and resulting in unknown effects to PNW species, habitats, and ecosystem. These impacts could extend to fisheries, human health, and the economy. Ongoing research and monitoring is focused on understanding this phenomenon to better prepare industry response and resource management actions (Feely et al., 2012).

Harmful algal blooms

Phytoplankton concentrations can become quite high in areas with sufficient nutrients, light, and water retention. Some types of phytoplankton produce toxins which can be harmful to marine organisms and humans at concentrated levels. For example, the diatoms of *Pseudo-nitzschia spp*. can produce the neurotoxin domoic acid, which causes amnesic shellfish poisoning, while the dinoflagellate *Alexandrium cantenella* produces the neurotoxin saxitoxin, which causes paralytic shellfish poisoning, and the dinoflagellates of the *Dinophysis spp* produce okadaic acid, which causes diarrhetic shellfish poisoning. When consumed by humans, these toxins can result in illness and even death (Office of National Marine Sanctuaries, 2008; Washington State Department of Fish and Wildlife, 2015b).

When levels of phytoplankton with toxins reach a particular threshold, the event is termed a harmful algal bloom (HAB). Shellfish that filter the organisms, such as clams and mussels, can concentrate the toxins exposing harmful levels to human consumers. The Olympic Region Harmful Algal Blooms Partnership (ORHAB), as well as coastal tribes cooperating with ORHAB, such as Quileute, regularly monitors phytoplankton levels in water and toxin levels in water and in shellfish tissue. The partnership is coordinated by the Olympic National Resources Center and consists of the Washington State Department of Health, Department of Fish and Wildlife, the Quinault Indian Nation, and others. The Quileute Tribe operates with separate funding, sends samples to WDOH, and results are posted through WDFW. When toxin concentrations reach a particular threshold, state beaches are closed to shellfish harvest to protect human health (Olympic Regional Harmful Algal Bloom Partnership, 2015; Washington State Department of Fish and Wildlife, 2015b). The Quileute Tribe posts advisories for its members on high levels of HAB at its website, on a hotline, and at trailheads for shoreline access.

The occurrence of HABs on the coast is considered to be a natural phenomenon. Nutrients and water retention in the Juan de Fuca Eddy create conditions for high productivity and can result in HABs.

Variable winds and upwelling/downwelling forces can push the Eddy closer to shore, bringing the HABs along the coast and contaminating shellfish harvest beaches, with higher toxin levels in the northern portion of the Study Area generally occurring during summer and fall. Southern WA coast beaches are also affected by HABs, with the Juan de Fuca Eddy and Heceta Bank (Oregon) suggested as possible primary sources of toxic phytoplankton (Hickey et al., 2013). The Columbia River Plume may act as a HAB barrier to southern WA beaches during the summer/fall, which can prevent accumulation of toxins in shellfish, but may also act as a HAB conduit during winter/spring resulting in shellfish closures (Hickey et al., 2013).

Suspected increases in the frequency of HABs along the Study Area could be related to the reduced outflow of the Columbia River Plume from dams and water removals, as well as climate related phenomena (Office of National Marine Sanctuaries, 2008). In 2015, the United States West Coast experienced possibly the largest HAB in recorded history, with HABs extending from central California to British Columbia and possibly as far north as Alaska. Unusually warm waters of the Pacific Ocean are thought to have contributed to this massive HAB (Doughton, 2015).

Chemical contaminants

Chemical contaminants such as metals, persistent organic pollutants, hydrocarbons, PCBs, etc. are also potential pollutants that can affect the health of marine waters. At present levels, these pollutants are not a concern within Sanctuary waters, and monitoring suggests that water quality is currently good throughout the Olympic Coast (Office of National Marine Sanctuaries, 2008). Grays Harbor is surrounded by commercial forestry and agriculture and has municipal and commercial point source discharge facilities. Water quality is monitored for various contaminants including metals, pesticides, and organic pollutants. In 1992 a TMDL was established for dioxin, a contaminant released into Grays Harbor as a by-product of pulp and paper bleaching from paper mills, and wasteload allocations for 2,3,7,8, TCDD (dioxin) were made for two facilities in Grays Harbor, one of which has since ceased operation. Dieldrin, a legacy pesticide, is listed as a Category 5 for a segment near Westport based on tissue samples from mussels (Washington State Department of Ecology, 2016).

Willapa Bay's surrounding watershed is mostly rural except for the cities of Raymond and South Bend. City industries include lumber mills and seafood processing and the river valley is dominated by agriculture with the surrounding area being mostly forestry. Willapa Bay is monitored for contaminants, including several pesticides and other pollutants. Chrysene, a compound from creosote for preserving wood, as well as Benzo(a)anthracene and Benzo(b)fluoranthene, both polycyclic aromatic hydrocarbons, are listed as Category 5 in limited segments of Willapa Bay based on results from mussel tissue samples. Willapa Bay has no other water or fish tissue contaminant TMDL listings (Washington State Department of Ecology, 2016).

Fecal Coliform Bacteria

Bacteria from human and animal waste can pose a threat to human health. Bacteria can enter the water from malfunctioning wastewater treatment plants, improperly functioning septic systems, and from livestock, pets, wildlife, and humans. As bacteria levels increase, so does the risk of humans becoming sick. When bacteria levels in water become high enough, swimming beaches and shellfish harvesting areas along state beaches are closed to protect human health (Washington State Department of Ecology, 2014c). Bacteria in shellfish growing areas and swimming beaches are routinely monitored by the Washington State Department of Health (DOH) in coordination with the Washington State Department of Ecology, tribes, and local partners.

A particular area of concern is the Pacific Coast Growing Area in Grays Harbor County, which extends north from Ocean Shores to Point Grenville. This area is approved for commercial shellfish harvest[5], and the portion from Moclips to Ocean Shores is a tourist destination and popular spot for recreational harvest of razor clams. Fecal coliform bacteria levels became high enough for the DOH to close two sections of the Mocrocks razor clam beach in the summer beginning in 2011, and a portion of the Copalis beach at Oyhut was closed year round to shellfish harvesting starting in 2013. Three zones within this area are listed as Category 5 on the state Water Quality Assessment (Washington State Department of Ecology, 2016). The Washington Department of Ecology is working with DOH, Grays Harbor County, and the Quinault Indian Nation to identify the source(s) of fecal coliform bacteria contamination within the area of concern. Potential sources of contamination in this area include stormwater, wastewater treatment plants, failing on-site septic systems near beaches and creeks, pet and horse waste, human waste from recreation activities, and wildlife waste (Swanson & Anderson, 2014).

Segments within Grays Harbor are listed as Category 4A on the state Water Quality Assessment for fecal coliform bacteria and there is a TMDL to address this issue. Bacteria levels have resulted in repeated temporary shellfish harvest closures for commercial shellfish growers in the central and western areas of the harbor that is approved for commercial shellfish harvest. The Grays Harbor Bacteria TMDL includes waste allocations for NPDES permitted sources of bacteria into the Harbor including: two seafood processors in Westport, Ocean Spray Cranberries, two pulp mills, discharges from sewage treatment plants in Aberdeen, Hoquiam, Ocean Shores, and Westport, and stormwater runoff from the cities of Hoquiam and Aberdeen. Load allocations were also established for nonpoint source pollution reductions for all tributaries to Grays Harbor including: the Chehalis River, Hoquiam River, Humptulips River, and the numerous smaller watersheds surrounding the harbor (Rountry & Pelletier, 2002).

Segments of Willapa Bay are listed as Category 5 in the state Water Quality Assessment for fecal coliform bacteria. The section of the bay at the mouth of the Willapa River is listed as 4a and is associated with the Willapa River Bacteria TMDL. The TMDL established wasteload allocations for NPDES discharges to the Willapa River and load allocations for nonpoint source reductions throughout the watershed including tributaries to Willapa River (Ahmed & Rountry, 2007). There is a prohibited commercial shellfish harvest area of the Bay at the mouth of and including the lower part of the Willapa River because of the WWTP, and an area at Bay Center is prohibited for commercial shellfish because of high fecal coliform samples in that area (Office of Environmental Health and Safety, 2015). Recent construction of a regional wastewater treatment plant (WWTP), and closure of the South Bend and Raymond sewage treatment plants, is expected to help improve bacteria and DO conditions in the Willapa River.

North of the Pacific Beach Growing Area ending at Point Grenville, monitoring efforts along the coast within the Sanctuary and in tribal U&As indicate that there is reduced concern for bacteria in these waters (Office of National Marine Sanctuaries, 2008).

Temperature

The Pacific Ocean and Washington coastal water temperatures are driven by large-scale oceanographic forces, upwelling, currents, and climatological factors. Average sea surface temperature ranges from about 8°C to 16°C (46°F to 61°F) annually. Sea surface temperature varies across the shelf

[5] There is no public access north of the Moclips River. Commercial harvest of razor clams is conducted by the Quinault Indian Nation.

(nearshore to offshore) due to local upwelling/downwelling forces (Pirhalla et al., 2009). At a larger scale, ocean temperature is influenced by climatic forces such as El Niño-Southern Oscillation and the Pacific Decadal Oscillation. In recent years, warm temperature anomalies ranging from 1°C to 4°C (2°F to 7°F) have been observed (the North Pacific Mode, aka “the Blob”) in the Pacific Ocean along the West Coast and are attributed to decreased cooling during the winter months (Bond et al., 2015; Hartmann, 2015). Ocean temperature is important to track because it influences species distributions, interactions, and survival, and changes in temperature may have important implications for commercially important and sensitive species (Andrews et al., 2013)

The shallow estuaries of Grays Harbor and Willapa Bay are influenced by upwelling/downwelling but are also subject to solar heating during the summer (Hickey & Banas, 2003). Both Grays Harbor and Willapa Bay are monitored for temperature water quality standards and have Category 2 (waters of concern) water segments, yet there are currently no temperature TMDLs for these estuaries. Grays Harbor segments with temperature increases beyond the water quality standards have been attributed to natural conditions (Washington State Department of Ecology, 2012a). Willapa Bay has several Category 2 temperature segments, and it is unclear to what extent natural conditions and human actions are influencing the temperature increases (Washington State Department of Ecology, 2012a).

Geomorphology

Washington’s coast resides in a tectonically active region, where the Juan de Fuca oceanic plate is subducting under the North American continental plate in what is known as the Cascadia Subduction Zone. This geologic activity has resulted in the creation of the Olympic Mountain range, the Cascade Mountain range, and the dynamic coastal cliffs along the northern coast. Up until about 5 million years ago, much of the material forming the present coastal mountain ranges and western Washington was under the ocean, at which time they began to be uplifted, as the oceanic plate slid under the continental plate. Today’s coastline is the result of erosion processes acting on the uplifted material over the past 5 million years, and is considered to be a relatively young landscape (Ruggiero et al., 2013).

Washington’s shoreline has a diverse physical landscape with dramatic coastal cliffs, rocky outcrops, expansive beaches, dunes, and pocket beaches separated by headlands (Map 3). The northern portion of the Washington coastline, from Neah Bay to Point Grenville, is dominated by rocky shores with short stretches of pocket beaches. Wave erosion has formed steep cliffs at various locations. In many places, wave cut platforms inundated by tides contain small islands, sea stacks, and rocks protruding from the platform surface (Olympic Coast National Marine Sanctuary, 2011; Ruggiero et al., 2013).

From Point Grenville south to Cape Disappointment on the Columbia River, the southern boundary of the Study Area, the coastline is dominated by broad sandy beaches, dunes, and ridges (Olympic Coast National Marine Sanctuary, 2011; Ruggiero et al., 2013). Coastal dunes are derived from sand carried by longshore drift and wind erosion (Skewgar & Pearson, 2011), and wetlands have formed behind the dunes in many areas (Hruby, 2014). The large estuaries in the southern portion of the Study Area, Grays Harbor and Willapa Bay, are fronted by large barrier spits, and have large expanses of wetlands. The Long Beach Peninsula, which consists mostly of the barrier spit separating Willapa Bay from the Pacific Ocean, is about 28 miles long.

Sediment is transported along the coast and nearshore areas by waves and currents. Winter storms generate large waves that push the sediment in a northerly direction, while calm summer waves transport sediment to the south. In the Columbia River Littoral Cell, which extends from Tillamook Head, Oregon to Point Grenville, Washington, the net sediment transport is to the north, particularly in the subcells north of the Columbia River (Washington’s coast). Storm events have caused localized, short term erosion in some areas. Anthropogenic changes such as jetties and dams have resulted in erosion and accretion changes to the beaches. Some locations are subject to chronic erosion, most notably the North Cove area just north of the mouth of Willapa Bay. This area has seen long term erosion rates (100 years) of about 30 meters (100 feet) per year, and short term erosion rates (20-40 years) of 56 meters (180 feet) per year. However, erosion areas like this are fairly limited and the vast majority of Washington's shoreline is currently stable or accreting over time (Ruggiero et al., 2013).

Washington's continental shelf is relatively narrow and extends about 7 to 35 nautical miles from the coast to the shelf break. The continental shelf is composed primarily of soft sediments and glacial deposits of gravel, including cobble and boulders, punctuated by rocky outcrops (Olympic Coast National Marine Sanctuary, 2011). The northernmost portion of the MSP Study Area south to the Hoh River consists of largely hard and mixed substrate, with rocky reefs and outcrops. From the Hoh River south to the Columbia River there is mostly soft, sandy substrate. Throughout the Study Area, outcrops may form rocky reefs scattered among the soft substrate (Map 3). Most notable is Grays Bank, a large rocky reef about 9 miles across the inner and middle shelf characterized by high habitat diversity. Seafloor modeling predicts that an unknown number of rocky outcrops could be scattered throughout the presumably mostly soft substrate of the Washington continental shelf (Goldfinger, Henkel, Romsos, Havron, & Black, 2014).

Empirical seafloor mapping within the Study Area is limited. Modeling efforts have attempted to create regional maps of geology and habitats to estimate the primary features and makeup of the seafloor. Data quality, confidence, and predictability vary by location and site specific mapping is recommended to accurately assess substrate and habitat features on a local scale (Goldfinger et al., 2014).

NOAA completed a seafloor mapping prioritization process for the Washington Marine Spatial Plan in 2015. This process evaluated existing seafloor data and prioritized locations within the Study Area where resource managers, scientists, and other stakeholders identified as being important for informing future management decisions. Two offshore and three nearshore priority areas were identified and represent opportunities to focus limited resources on key mapping needs. Ecosystem-based management, living resource management, coastal inundation & natural coastal hazards, "other regulatory", sediment management, and research were identified as the most important management issues for these areas (NCCOS, 2015). The final prioritization report can be found at http://www.msp.wa.gov/wp-content/uploads/2015/03/NCCOS_SeafloorMappingReport.pdf.

The Study Area also includes the shelf break and slope (a.k.a. coastal margin), a transition zone between the oceanic plate and the continental plate, which rapidly increases in depth toward the abyssal plain. Several submarine canyons cut into Washington's continental slope and shelf, including the Nitinat, Juan de Fuca, Quinault, Gray's, Guide, Willapa, and Astoria Canyons (Hickey, 1995) (Map 3). The canyons vary in size, with the Juan de Fuca canyon trough transecting the northern portion of the Study Area angling toward the Strait of Juan de Fuca. Submarine canyons are regions for massive submarine landslides and act as channels for coastal sediment to reach the deep seafloor (Olympic Coast National Marine Sanctuary, 2011). Submarine canyons are also noted to be habitats with high biological activity and diversity (Hickey, 1995). Canyons can enhance coastal upwelling by providing a conduit for deep, cold, nutrient rich seawater to reach the bottom boundary layers of shelf water, where it can be upwelled by local wind forcing, contributing to the high productivity of Washington's ocean (Hickey & Banas, 2008).

Earthquakes and tsunamis

The Cascadia Subduction Zone (CSZ), located along the West Coast, from northern Vancouver Island down to northern California, is a region full of active earthquake faults. The Juan de Fuca Plate is subducting underneath the North American Plate, which causes friction and stress. Scientists believe the two plates are currently locked, so that a major earthquake has not occurred. Eventually when the stress becomes too great, the major faults will rupture, causing significant earthquakes. There are three different types of earthquakes: deep, shallow, and subduction zone.

In the 1980s, scientists became aware of the risk of "great" subduction zone earthquakes in the Cascadia region. Geologic records revealed that in 1700, an approximate magnitude 9.0 (Richter scale) earthquake occurred in the CSZ, and further investigations revealed that a similar great earthquake occurs on average every 500 years in the Cascadia region (Cascadia Region Earthquake Workgroup, 2013). Smaller CSZ earthquakes are thought to occur off the northern California and Oregon coasts (Goldfinger et al., 2012).

The next great CSZ earthquake is anticipated to be a magnitude of 8.0 to over 9.0. It will cause substantial damage, particularly to coastal areas, and may result in several large tsunamis. During a CSZ earthquake, a portion of the seafloor is suddenly thrust upwards, which displaces the entire ocean above it, resulting in long period waves radiating outward from the source. Multiple waves can be generated, and travel up to about 500 miles per hour through the deep ocean. Recent examples of subduction earthquakes and associated tsunamis in other areas of the world include the 2011 magnitude 9.0 Tohoku, Japan earthquake and the 2010 magnitude 8.8 Maule, Chile earthquake (Cascadia Region Earthquake Workgroup, 2013).

Biology

MSP Study Area waters have high biological productivity and support a diversity of habitats and species, many of which are important ecologically, culturally, and economically to Washington, the United States, and the world[6]. Habitats are where organisms live, eat, shelter, and reproduce. A living ecosystem is the collection of habitats, and healthy marine habitats are the foundation of healthy communities of marine life. The MSP Study Area is comprised of many habitats which support numerous species of fish, mammals, and birds. This section describes the key habitats and species found within Study Area waters to tell the story of marine life off of Washington's Pacific coast and to emphasize the importance of protecting these biological resources now and into the future.

As a part of the marine spatial planning process, scientists at NOAA developed conceptual models of the key ecological components, physical drivers, and human activities in the MSP Study Area. They also evaluated and selected a portfolio of indicators for the key components and quantified the status and trends of the indicators. The results are presented in the following two reports, which are used as frequent references for this section. Readers are encouraged to consult the reports for references to the original research.

- Andrews, K. S., Coyle, J. M., & Harvey, C. J. (2015). Ecological indicators for Washington State's outer coastal waters. Seattle, WA: Northwest Fisheries Science Center. Report to the Washington Department of Natural Resources. Retrieved from http://www.msp.wa.gov/wp-content/uploads/2015/03/NWFSC_EcosystemIndicatorReport.pdf.
- Andrews, K. S., Harvey, C. J., & Levin, P. S. (2013). Conceptual models and indicator selection process for Washington State's marine spatial planning process. Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic & Atmospheric Administration. Retrieved from http://www.msp.wa.gov/wp-content/uploads/2013/07/NOAA_NWFSC_ConceptualModel_FinalReport.pdf.

[6] Olympic National Park is a UNESCO World Heritage Site.

Habitats

Several habitats occur within the MSP Study Area. For the purposes of this MSP, six major habitat types are described: pelagic, seafloor, kelp forest, rocky shores, sandy beaches, and large coastal estuary habitat. These habitat categories were chosen by the National Marine Fisheries Service Northwest Fisheries Science Center for the Indicators for Ecological Assessment reports (Andrews, Coyle, & Harvey, 2015; Andrews et al., 2013) produced for the WA MSP and were derived from categories used in WDFW's "State of the Washington Coast" (Skewgar & Pearson, 2011) and the Olympic Coast National Marine Sanctuary "Condition Report" (Office of National Marine Sanctuaries, 2008). The indicators and report are discussed in further detail in Section 3.

Pelagic

The pelagic zone represents all water column habitats from the surface to near-bottom in MSP Study Area waters. Physical drivers important to the pelagic habitat include currents, eddies and plumes, wind-driven upwelling, climatic forces, and solar energy. These forces create a dynamic pelagic zone, which in turn affects primary productivity, pelagic community composition, and species survival. For more information on these forces in the MSP Study Area, please see the Physical Oceanography section.

Phytoplankton are the base of the food web for the entire marine community. The phytoplankton community off the Washington coast is highly productive due to strong upwelling of nutrient-rich waters and the influence of the Juan de Fuca Eddy and the Columbia River plume. Diatoms and dinoflagellates generally dominate the phytoplankton communities (Andrews et al., 2013).

Many zooplankton migrate vertically in the water column from near the seafloor to the surface to feed on phytoplankton. Zooplankton are key links in the food chain, connecting primary production to upper trophic levels. Shifts in zooplankton species composition can be correlated with regional climate and seasonal patterns. Cold water zooplankton species tend to be lipid-rich, providing a key energy source to pelagic fishes, while warm water zooplankton have a lower lipid concentration and can be a lower quality food source. Cold water species typically dominate the zooplankton community during the summer upwelling season, while the warm water species usually dominate during winter. Climate forces such as El Niño events, the 'Blob', and the Pacific Decadal Oscillation can alter these seasonal patterns (Andrews et al., 2015, 2013).

The pelagic zone provides important habitat and food for a variety of fishes. Forage fish species, including smelt, Pacific herring, northern anchovy, and Pacific sardine, live and feed in the upper pelagic zone and are key links in the food web by transferring energy from plankton to larger predatory fish, marine mammals, and seabirds. Salmon also spend much of their time in the pelagic zone after their initial entry into the ocean, feeding on zooplankton (e.g. pteropods) and forage fish. Albacore tuna are seasonal visitors to the MSP Study Area. Midwater rockfish, such as adult widow rockfish (*Sebastes entomelas*), Pacific ocean perch (*S. alutus*), yellowtail rockfish (*S. flavidus*), and black rockfish (*S. melanops*), spend a large portion of their time above the seafloor substrate and feed primarily on large zooplankton. Pacific whiting (a.k.a. hake) are one of the most abundant fish species in the California Current. They also feed in pelagic waters on prey items similar to salmon, rockfish, and other groundfish species (Andrews et al., 2013). Myctophids (a.k.a. lanternfishes) may be the most abundant pelagic family of fishes. Like many zooplankton, they occupy deeper waters during the day and rise to feed on phytoplankton providing an important trophic link between primary production and deeper waters (Davison, Checkley Jr., Koslow, & Barlow, 2013).

Many species of seabirds and marine mammals feed and transit through the pelagic habitat of the MSP Study Area. At least 29 species of marine mammals inhabit or transit through Washington coastal and offshore waters, and numerous species of marine birds live, reproduce, feed, and transit through the MSP Study Area, some migrating thousands of miles to "winter" in MSP waters. These animals feed on zooplankton, forage fish, salmon, and other fishes (Andrews et al., 2013; Olympic Coast National Marine Sanctuary, 2011). Occasionally, leatherback sea turtles also feed in the pelagic habitat of the MSP Study Area, preying mainly upon jellyfish (Washington State Department of Fish and Wildlife, 2013).

Primary existing human pressures within this habitat include fishing, atmospheric deposition of pollutants, and commercial shipping activities (Andrews et al., 2013).

Seafloor

Seafloor habitat represents all bottom habitats below 30 m (98 feet) depth in the MSP Study Area[7]. Physical seafloor habitat can consist of soft/mixed substrates or rocky/mixed substrates. Empirical mapping of the entire MSP Study Area seafloor habitat is not available. However, direct seafloor mapping of limited areas along with models suggest that the majority of seafloor habitat is soft/mixed substrates (Goldfinger et al., 2014). Rocky/mixed seafloor substrates mainly occur in the northern portion of the Study Area (Map 3). Biogenic seafloor habitat made up of deep-sea corals, sponges, and anemones has also been observed in the Study Area, with fishes and invertebrates congregating in these areas. In the MSP Study Area, while the entire area has not been surveyed to date, the highest density of biogenic habitat has been observed in the canyon areas such as the northernmost region in the Juan de Fuca Canyon area, although many areas with biogenic habitat have been observed throughout the Study Area (Andrews et al., 2015).

Large zooplankton such as euphausiids (a.k.a. krill) are an important component to the seafloor habitat food web as they are a large portion of the diet for many groundfish. The abundance of predominant krill species has been observed to be much higher during high upwelling conditions than low upwelling conditions. Sinking microscopic aggregates of organic and inorganic particles such as bacteria, phytoplankton, detritus, fecal pellets, and bio-minerals, are also an important component of the seafloor food web. Aggregates of this material fall from the pelagic zone to the seafloor as "marine snow", where they become food for detritus-feeding invertebrates and deposit feeders. Peaks in marine snow are commonly observed following large diatom blooms (Andrews et al., 2013).

Deposit feeders live and feed on the seafloor. Species include several benthic invertebrates including amphipods, isopods, small crustaceans, snails, sea cucumbers, worms, polychaetes, sea slugs, and hermit crabs. They feed primarily on detritus on the seafloor, and are key links in the food web. Deposit feeders are prey for several commercially or recreationally valuable species, including Dover sole (*Microstomus pacificus*) and Pacific halibut (*Hippoglossus stenolepis*). Other benthic invertebrates include bivalves, corals, sea urchins, and sea stars, which make up significant proportions of some flatfish and rockfish diets. The seafloor is also important habitat for Dungeness crab (*Metacarcinus magister*), a highly valuable commercial fishery and important prey for sharks, large rockfish, and octopus. Spot prawns (*Pandalus platyceros*) and pink shrimp (*P. eous* and *P. jordani*) are also commercial harvest species associated with the seafloor habitat (Andrews et al., 2013).

Groundfish provide one of the primary fisheries for Washington coastal communities. The groundfish assemblage consists of many different families, including rockfish, roundfish, flatfish, and elasmobranchs. These species rely on seafloor habitat and their diets consist of many benthic

[7] This seafloor depth cutoff was chosen in the Ecological Indicators report. For more details, please see Andrews et al., 2015.

invertebrates and other fishes. Commercial fishing and associated seafloor habitat modification from trawls and other bottom gear are key human pressures in this habitat.

A physical stressor to the seafloor habitat includes low dissolved oxygen events (hypoxia and anoxia) that can cause stress and mortality of organisms along the seafloor, especially immobile or slow-moving benthic invertebrates that are unable to leave the area during low oxygen conditions. This may affect the seafloor food web and possibly impact the groundfish assemblage (Andrews et al., 2013). Monitoring suggests that hypoxic conditions have been increasing in frequency and intensity since 2000 (Chan et al., 2008). For more information, please see the Dissolved Oxygen section.

Kelp forest

Kelp forest habitat includes floating kelp canopies of bull kelp (*Nereocystis leutkeana*) or giant kelp (*Macrocystis pyrifera*), submerged kelp beds (e.g., *Laminaria* spp. and *Pterogohora californica*), and rocky reefs that occur at depths of less than 30 meters (98 feet). Rocky reefs are included in the kelp forest habitat category because many animal species that inhabit kelp forests also inhabit shallow rocky reefs without canopy-forming kelp. In addition to the two conspicuous species of canopy-forming kelp, more than 20 species of kelp that do not form floating canopies occur on rocky reefs in the region, comprising one of the most diverse kelp communities in the world (Mumford, 2007). This habitat occurs primarily along the northern coast of the MSP Study Area (Map 4)(Andrews et al., 2015).

Kelp forests form diverse communities providing physical structure and energy to the food web. Kelp provides surface area, creating habitat for sessile organisms. The complex structural component of kelp serves as a nursery, refuge, and forage area for a variety of fishes, especially rockfish, sculpins, greenling, lingcod, perch, juvenile salmon and others, including many fish on Washington's list of Species of Concern. Floating kelps provide surface habitat that dampens waves, and these semi-protected areas are used as foraging habitat for seals and several species of birds. Sea otters feed in kelp habitats and rest among floating kelp beds (Andrews et al., 2013).

Kelp forests and other macroalgae also play a key role in supplying particulate organic matter and dissolved organic matter to the food chain. Decomposing kelp supports a strong bacterial community that fuels phytoplankton and benthic filter-feeder growth in the nearshore environment. In addition, sections or entire plants break loose during storms and sink to the bottom or wash up on beaches, where they are scavenged by small crustaceans, insects, and other scavengers (Mumford, 2007).

The total extent of surface canopy, area, and density of kelp beds affects the species assemblages found in this habitat. Trends in kelp bed characteristics thus provide insight into ecosystem condition and also provide important information for trends in fish and invertebrate populations. Kelp populations fluctuate seasonally and inter-annually depending upon reproductive cycles, oceanographic conditions, and herbivore pressure. Strong storm events and nutrient-poor waters associated with El Niño events can decrease kelp coverage, while cold, nutrient-rich La Niña events provide extraordinary growth conditions. Disturbance from storm-driven waves is, however, a natural process and provides an important opportunity for bull kelp and macroalgae recruitment. Years with suppressed cold water upwelling can negatively affect kelp forests, as bull kelp is particularly sensitive to warm temperatures. Light penetration is also an important physical factor, and events with increased sediment runoff due to heavy rains or landslides may reduce densities of bull kelp (Andrews et al., 2013).

In the northern hemisphere, the most widespread and herbivore-induced kelp deforestations have resulted from sea urchin grazing (Steneck et al., 2002). Three common sea urchin species: red (*Mesocentrotus franciscanus*), purple (*Strongylocentrotus purpuratus*), and green (*S. droebachiensis*) graze upon kelp in Washington. Sea urchin abundance is controlled by predation, and the most notable predators of sea urchins are sea otters, seastars, humans, and crabs. Sea urchin removal by sea otters can promote the growth of kelp and kelp-associated communities. Sea otters have ecosystem-level effects across the nearshore marine communities they inhabit, and this sea urchin/sea otter/kelp trophic interaction has been well documented in the Pacific Ocean (as cited in Andrews et al., 2013). In Washington waters, sea otter reintroduction and range extension was followed by decreases in sea urchin densities and increases in algal abundance (Kvitek, Iampietro, & Bowlby, 1998; Laidre & Jameson, Ronald J., 2006).

Existing human pressures identified in the Ecological Indictors report for MSP for kelp forest habitat include recreational fishing, pollutants, and excess nutrient inputs (Andrews et al., 2015). Increases in water temperature have been shown to negatively impact kelp (Dayton, 1985; Tegner, Dayton, Edwards, & Riser, 1996), and anthropogenic climate change is expected to negatively affect kelp communities (Harley et al., 2012). Turbidity and sedimentation profoundly affect kelp communities by changing light availability, scouring plants or burying hard substrate (Shaffer & Parks, 1994) (Branch et al. 1990, Airoldi 2003).

Rocky shores

The rocky shores habitat represents rocky and mixed intertidal shorelines in the MSP Study Area. This habitat generally occurs north of Point Grenville (Map 3) (Andrews et al., 2015). Rocky shores cover a broad range of substrate types, from bedrock to boulder fields to cobble and gravel. Tide pools, boulder size, and proximity to sand can influence the communities within this habitat (Andrews et al., 2013).

The variety in substrate type, tidal elevation gradient, productivity, and local physical disturbances (storms, drift wood, etc.) lead to a wide diversity of macrophytes in this habitat. Over 120 species of macrophytes (macroalgae, surfgrass, etc.) have been documented to occur in rocky habitats within the Olympic Coast National Marine Sanctuary (OCNMS). Macrophytes not only provide food, but also provide microhabitats for fauna, protecting them from stressors such as waves, desiccation (drying out), and temperature changes. This habitat also supports a large biomass of sessile, suspension-feeding benthic invertebrates. Suspension-feeding taxa include barnacles, mussels, sponges, tubeworms, tunicates, and others. The upper and lower distribution limits within the intertidal zone for each species depends upon their resilience to physical factors such as desiccation and temperature, along with competition and predation. Suspension feeders provide habitat for macroalgae, invertebrates, and fish, can influence nutrient concentrations in intertidal waters, and provide food for predators including humans (Andrews et al., 2013).

Dozens of grazing invertebrates occur along the rocky shores of Washington's outer coast, most notably snails, limpets, chitons, and small crustaceans. Grazers are also stratified in their vertical distribution limits within the intertidal zone. As a group, grazers feed on a variety of organisms including benthic microalgae, coralline algae, macroalgae, and algal detritus. Predators within the rocky shores habitat include the ochre seastar (*Pisaster ochraceus*), whelks, anemones, worms, and crabs. *Pisaster* is considered a keystone predator and its presence helps to maintain the diversity of intertidal rocky communities. Zonation and microhabitat preferences are also exhibited by predators on rocky shores (Andrews et al., 2013).

Several fishes live within rocky shores, moving in and out with the tides and residing in tide pools. Common species include small sculpins and gunnels. Many seabirds, shorebirds, raptors, and general foraging bird species use rocky shores. Oystercatchers, gulls, and crows forage within the rocky intertidal zone. Species such as petrels, cormorants, gulls, and murres nest in colonies on offshore rocky islands and sea stacks. Harbor seals (*Phoca vitulina*) are common in rocky intertidal habitats along the outer coast, and are year-round residents. Rocky islands are also used as haul-outs for Steller sea lions (*Eumetopias jubatus*) and California sea lions (*Zalophus californianus*). Northern elephant seals (*Mirounga angustriostris*) have been observed occasionally at some rocky islands (Andrews et al., 2013).

Several important physical drivers influence the rocky shores habitat. The intertidal zone is defined by the tides. Geomorphology and tidal elevation determine which zones are exposed to various stressors and the length of time they are exposed. Stressors include exposure to air, temperature changes, predation, and changes in freshwater inputs, wave action, and light. Organisms that tolerate similar conditions and tidal exposures will group together (aka zonation). The upper limit of a species distribution is often determined by their tolerance to physical extremes, while the lower limit is often determined by forces such as competition and predation. Rocky intertidal organisms are also subject to wave energy, which can cause physical disturbance, particularly during severe storms. It is also suggested that wave energy increases the productivity of rocky intertidal systems by providing competitive advantages for wave tolerant organisms, replenishing nutrients, and enhancing light uptake by algae. Upwelling provides nutrients, plankton, and larval recruits to the rocky intertidal system (Andrews et al., 2013).

Rocky shores along the coast of Washington appear to be healthy. There are, however, several existing human pressures that could impact the health of rocky shores. Specific activities include trampling and harvest by human visitors, competition from non-native species, and pollution, including but not limited to oil spills, marine debris, and untreated discharge from land or marine facilities or activities (Andrews et al., 2013).

Sandy beaches

Sandy intertidal beach habitat stretches mainly along the southern shorelines of the MSP Study Area, south of Point Grenville, making up about half of Washington's outer coastline. Sandy pocket beaches between headlands and near estuaries occur also north of Point Grenville (Map 3). Physical drivers for sandy beach habitats are sediment deposition, wave energy, beach slope, upwelling, and climate variability. Upwelling provides nutrients and food to the beach habitat. Weather and climate, such as hot sunny days and strong winter storms, create variable conditions for organisms living in sandy habitats (Andrews et al., 2013).

Physical forces are central to the ecology and functioning of sandy beaches. Wave energy, the size of sand grains, and the elevation gradient interact to shape sandy beach systems. Washington's southern beaches are generally characterized as dissipative, meaning they are relatively flat, and have fine sand, large tide ranges, and broad surf zones (Andrews et al., 2013; Skewgar & Pearson, 2011). The wave energy reaching and shaping a particular stretch of beach will vary depending upon factors such as proximity to headlands and bays, winds during storms, and offshore structures such as islands, reefs, or sea stacks (Andrews et al., 2013).

Primary producers within sandy habitats are surf zone phytoplankton, benthic diatoms, and other small autotrophs. The razor clam (*Siliqua patula*) is an invertebrate commonly associated with Washington's sandy beaches. Razor clam digging is a popular recreational activity along the coast, providing significant economic benefits. Razor clams are also likely important ecologically, as they recycle ammonium into the nearshore water, promoting primary production. Other invertebrate macrofauna within Washington's sandy beach habitat include several crustaceans such as shrimp, crabs, and amphipods, along with polychaetes, snails, and isopods that live in the middle to lower tidal elevations. Higher on the beach near the drift line are crustacean scavengers such as beach hoppers and isopods, as well as terrestrial arthropods. Sandy beaches are also habitat for several meio- and microfaunal invertebrates (e.g. small worms, mollusks, cnidarians, and unicellular heterotrophs), although not many studies have been conducted to characterize these communities on Washington's beaches (Andrews et al., 2013).

An important ecological interaction in the sandy beach habitat is the importation of phytoplankton, particulate organic matter, and detritus. Organic matter brought in by waves and currents provide substantial support for the food chain. In addition, detached kelps and other macrophytes wash up as wrack on the beach and provide habitat for invertebrates and fish as well as food sources for foragers. Habitat structure of sandy beaches (beach zonation, grain size, wave energy, and moisture content) also heavily influences community composition. It is hypothesized that dissipative beaches (like those in Washington) support a greater diversity of microhabitats and niches than intermediate and reflective (steep slopes, coarser sand, no surf zones, etc.) beaches (Andrews et al., 2013).

Dozens of species of fish inhabit subtidal waters along sandy beaches in Washington. Some, such as surf smelt, spawn in intertidal sand substrate. Common fish include sculpins, sand lance, surf perches, juvenile tomcod, and flatfish. Birds, including gulls, diving birds, wading birds, shorebirds, and crows, forage on sandy beaches at high and low tides. Sandy beaches are also visited by foraging terrestrial mammals (Andrews et al., 2013; Skewgar & Pearson, 2011).

Sand dunes occur along many of the sandy beaches of Washington's outer coast. Vegetated dunes are colonized by native or introduced dunegrasses and various small shrubs and trees. Dunes provide habitat for shorebirds such as sanderlings and snowy plover (*Charadrius nivosus*) (Skewgar & Pearson, 2011). The beaches north of Kalaloch are often characterized by the buildup of large logs that have either eroded off of adjacent forested cliffs, or been carried down river systems to the coast. Dunes also provide important protection to the shoreline from wave and storm erosion.

Many existing human activities may affect Washington sandy beaches, including clamming and recreation, shoreline development, non-native species, sediment changes, oil spills, and pollution. Sandy beaches south of Point Grenville receive most of their sand from the Columbia River; therefore, dams and disposal of dredged sand from the mouth of the Columbia River into offshore waters have greatly decreased the sediment source from the Columbia River to these beaches (Andrews et al., 2013). This is adversely affecting beach habitat north of the Columbia's mouth, since materials removed by erosive action are not replaced.

Large coastal estuaries

Coastal estuaries are semi-enclosed, brackish bodies of water that form where rivers meet the ocean. They are highly productive ecosystems that support a wide range of species at different life history stages, along with numerous ecosystem services. They are also important transitional systems that are linked to freshwater, terrestrial, and marine processes. In particular, this habitat discussion focuses on Willapa Bay and Grays Harbor, the two largest coastal estuaries in the MSP Study Area (Andrews et al., 2015).

Large coastal estuaries have varying sediment types (gravel, sand, mud, or silt). Grays Harbor and Willapa Bay have vast areas of mudflats below salt marshes or terrestrial vegetation, cut with multiple tidal channels. Wave exposure varies by location, with sand flats replacing mud flats in areas more exposed to coastal wave energy. Washington's large coastal estuaries are significantly influenced by ocean upwelling and downwelling. Salinity varies with proximity to rivers and bay mouths, and ocean forces and tides can break up the stratification of freshwater on the surface and saltwater below. Freshwater inputs are highest in the winter and lowest in the summer. Tidal mixing is a key driver in this habitat, as over 50% of Willapa Bay and Grays Harbor is intertidal (Hickey & Banas, 2003; Skewgar &

Pearson, 2011). Other physical drivers include sediment dynamics, river plumes, large-scale climate patterns, and weather (Andrews et al., 2015).

Estuaries are critical habitat for a variety of marine and terrestrial organisms. Primary producers include phytoplankton, benthic microalgae, macroalgae, and macrophytes, such as eelgrass, kelp, salt marsh plants (Map 4), and terrestrial plants. Salinity and tidal elevation influence the distribution of plants throughout the estuaries, with the upper estuarine habitat host to a variety of plants, and mudflats being mostly unvegetated. Invertebrates include insect larvae, amphipods, polychaetes, burrowing shrimp, and others (Skewgar & Pearson, 2011)

Shellfish and fish are abundant here. Specific shellfish species include the Olympia oyster (*Ostrea lurida*)[8], non-native Pacific oyster (*Crassostrea gigas*), non-native manila clam (*Venerupis philippinarum*), Dungeness crab, and others. Numerous listed and commercially important fishes spend at least some part of their life-cycle within estuaries. Specific fish species include six species of salmon (*Oncorhynchus* spp.), herring, three-spined stickleback (*Gasterosteus aculeatus*), sturgeon (*Acipenser* spp.), sevengill sharks (*Notorynchus cepedianus*), and many others. Estuaries provide crucial nursery habitat for many species of juvenile fishes and crabs. Some studies have evaluated the spatial and temporal use of the estuaries by juvenile salmon (Sandell, Fletcher, McAninch, & Wait, 2013). Estuaries are also important foraging areas for visiting wildlife, such as migratory shorebirds, ducks, and geese, as well as terrestrial animals, such as deer and elk. Harbor seals also reside within coastal estuaries, hauling out on rocks, reefs, beaches, and docks, and feed on invertebrates and fishes in marine, estuarine, and occasionally fresh waters (Andrews et al., 2015; Skewgar & Pearson, 2011).

Biogenic habitats are an important part of the coastal estuarine ecosystem. Eelgrass beds and oyster reefs are two types of biogenic habitats that are very common in Grays Harbor and Willapa Bay. Native and non-native eelgrass (*Zostera marina* and *Z. japonica*, respectively) form patchy beds covering thousands of hectares in these coastal estuaries (Map 4). Non-native eelgrass grows on shallow, intertidal areas whereas native eelgrass typically grows deeper. Eelgrass beds provide primary production to the nearshore food web, and creates a physical habitat that provides three-dimensional structure to otherwise bare mudflats, slows water currents, dampens waves, and traps sediments (Abdelrhman, 2003; Skewgar & Pearson, 2011). Eelgrass is a key part of the estuarine food web, for several species, including birds, invertebrates, and fish. For example, Brant geese (*Brandt 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 (Ganter, 2000; Skewgar & Pearson, 2011). Seagrass provides habitat for epiphytes, microalgae, macroalgae, and invertebrates that attach to its leaves and are preyed upon by fish and marine-associated birds. Eelgrass habitat is also vital for several highly important commercial species, such as Dungeness crab, Pacific herring, salmonids, shrimp, and flatfishes at some point in their life-cycle (Skewgar & Pearson, 2011).

Oysters also create a three-dimensional biogenic habitat in the lower intertidal and subtidal zones. Fish and invertebrates live within oyster shell accumulations, and the oysters provide ecosystem functions by circulating and clarifying water, reducing hypoxia, and filtering nutrients. Historically, Willapa Bay and Grays Harbor supported large populations of Olympia oysters in the low intertidal zone and the shallow subtidal zone (Skewgar & Pearson, 2011). After overharvest led to commercial extinction by 1930, recovery of the Olympia oyster has been hindered by removal of shell accumulations, the preferred habitat of Olympia oyster larvae, and competition with non-native oyster species. Recent aquaculture has focused on the non-native Pacific oyster(Ruesink et al., 2005; Skewgar & Pearson, 2011).

[8] The Olympia oyster is also a Washington State Candidate Species on the Species of Concern List

Several existing human pressures occur within Washington's large coastal estuaries including fishing, pollution (both physical, such as suspended sediment or temperature increases, and chemical, including by not limited to acidification), dredging, shellfish aquaculture, non-native species, watershed activities, port development, and commercial shipping (Andrews et al., 2015). While the estuaries provide valuable habitat functions and ecosystem services, there is an extensive history of human activities and management within Willapa Bay and Grays Harbor, which has significantly altered habitats and functions from their original state.

Estuaries are highly valuable ecosystems. While the MSP has spatial data for some estuarine species and habitats (e.g. green sturgeon critical habitat, marine mammal haulout locations, seabird colonies, dunegrass, kelp, seagrass, and saltmarsh), up-to-date spatial data for many estuarine species is not available. However, given the context that estuaries are known to be vital habitat for many commercially and recreationally valuable species, wildlife, endangered and threatened species, and support key human uses, the State has determined that Willapa Bay and Grays Harbor estuaries are highly important ecological areas, and therefore will be subject to the strictest evaluation if proposals for new uses are suggested within these estuaries. For more information on the Ecologically Important Areas analysis please see Part 3.

Species

The MSP Study Area is home to many species of marine animals and plants. Various species are important for commercial and recreational fisheries, are key links in the marine and estuarine food web, are popular for wildlife viewing, may be state and/or federally protected, or are simply important to the quality and character of the region's ecosystem. This section highlights animals: key fishes, marine mammals, birds, and sea turtles that occur within the MSP Study Area to help tell the biological story of Washington's ocean and estuaries. Many other taxonomic groups such as invertebrates, zooplankton, phytoplankton, algae, and plants are also important to the MSP Study Area. While these taxa are not specifically described here, many are mentioned briefly within the Habitat Section.

Fishes

The MSP Study Area is habitat for a variety of fishes. Fishes are important both ecologically and economically to the state of Washington. Key groups of fishes discussed here are pelagic fishes, groundfish, and salmonids and other anadromous fish.[9] Map 5 shows the Ecologically Important Areas (EIA) for the fish subsector.[10]

Forage fish, migratory species, and pelagic fishes

Forage fish are important links in the ocean food web, connecting primary and secondary trophic levels to larger predatory fish, marine mammals, and seabirds. Several species of forage fish inhabit the MSP Study Area (Table 2.1-1). Forage fish tend to be present in high abundance, feed on plankton for a portion of their life cycle, and form dense schools or aggregations. Forage fish often feed in pelagic waters, and certain species such as smelt and sand lance spawn on coastal intertidal sandy beaches (Map 6). Forage fish are prey for a variety of commercially important and legally protected fish (i.e. salmon), marine mammals, and birds and can be of interest for commercial, recreational, and subsistence fishing (Andrews et al., 2013; Langness, Dionne, Masello, & Lowry, 2015).

Table 2.1-1. Forage fish species

[9] Information on fishing is in Section 2.4: Commercial, Recreational, and Tribal Fisheries.
[10] Details of the EIA analysis and maps are provided in Part 3: Spatial Analyses.

Common name	Species name
Surf smelt	*Hypomesus pretiosus*
Night smelt	*Spirinchus starksi*
Whitebait smelt	*Allosmerus elongates*
Pacific sand lance	*Ammodytes hexapterus*
Pacific herring	*Clupea pallasii*
Northern anchovy	*Engraulis mordax*
Pacific sardine	*Sardinops sagax*

Many migratory fish species travel through and feed within the pelagic waters of the MSP Study Area including species such as common thresher shark and albacore tuna. These species feed at a variety of levels on the food chain, from plankton, to fishes, to mammals. Migratory species are important commercial, recreational, and tribal fisheries and because of their migratory nature can be fished by vessels from multiple nations (Olympic Coast National Marine Sanctuary, 2011; Pacific Fishery Management Council, 2015). Pelagic fish species are susceptible to climate variations, such as upwelling, source waters, and El Niño/La Niña events (Andrews et al., 2013).

Groundfish

The groundfish (a.k.a. bottomfish) assemblage consists of dozens of species including rockfish, lingcod, dogfish, halibut, whiting, flatfish, skates, and sablefish. Rockfish consists of numerous species, with 30 species identified by NOAA in MSP waters. Over 15 species of flatfish have been identified in OCNMS waters. Groundfish occupy several habitats, including rocky bottoms, kelp, seafloor, and even pelagic areas. Groundfish prey on a variety of organisms such as euphausiids, plankton, deposit feeders, benthic invertebrates, forage fish, and other small groundfish (Andrews et al., 2015, 2013; Olympic Coast National Marine Sanctuary, 2011).

Fishing has been a human pressure affecting groundfish and many species were subject to overfishing, especially during the 1980s and 1990s. Some rockfish species like Yelloweye Rockfish are particularly sensitive to fishing pressure because of long-lived, low productivity life history characteristics. A few stocks of rockfish within MSP Study Area waters have been declared overfished since 2000, but recent fishery management measures appear to have been successful at rebuilding most groundfish stocks, with only two stocks still classified as 'overfished' (yelloweye rockfish and pacific ocean perch) (Garfield & Harvey, 2016; Pacific Fishery Management Council, 2014a). Essential fish habitat and rockfish conservation area closures for groundfish bottom trawling have been established and are being reconsidered in several areas within the MSP Study Area to protect habitat and aid in stock recovery. The status of groundfish populations is monitored and assessed by NOAA Fisheries, tribes, and state fisheries management agencies. However, there are data gaps in monitoring of rockfish populations due to the difficulty and cost of conducting routine, scientific surveys in rocky reef habitats which are difficult or not possible to access with bottom trawl gear used for stock assessments.

Salmon and other anadromous fishes

Salmonids (salmon and related species) and other anadromous fishes are of high ecological and economic importance in Washington. Anadromous species spawn in freshwater systems, migrate to nearshore and offshore marine areas to feed and grow, then return to home rivers and streams upon maturity to start the cycle again. Seven salmonids, Pacific eulachon, green sturgeon, white sturgeon, and Pacific lamprey occur within the MSP Study Area (Table 2.1-2). American shad is a non-native anadromous species that was introduced to the West Coast in the late 1800s and has thrived. Eight of the twelve anadromous species in the MSP Study Area are listed under the federal Endangered Species Act (ESA) or Washington State species of concern lists (Washington State Department of Fish and Wildlife, 2015d).

Salmon in particular are a cultural icon to Washington residents, both tribal and non-tribal. After leaving freshwater, salmon rely on estuarine (Sandell et al., 2013), nearshore, and pelagic waters and prey on a variety of animals including euphausiids, amphipods, larval decapods, and forage fish (Andrews et al., 2015, 2013).

Salmon have been and continue to be impacted by numerous pressures: fishing, loss of freshwater habitat, hydropower dams, and poor ocean conditions, which collectively can include changes in chemical or physical conditions, with accompanying loss of food supply (NOAA Fisheries, 2014c). Salmonids are considered for listing and recovery under the ESA below the species level as Evolutionary Significant Units (ESUs). The MSP Study Area provides habitats for several listed (e.g. Puget Sound Chinook) and non-listed (e.g. Washington Coast Chinook) ESUs. Much of the critical habitat designated for each of the listed salmon ESU's lies outside of the Study Area. Lake Ozette sockeye salmon and some Columbia River salmon ESUs, and critical habitats are directly adjacent to the Study Area. Essential Fish Habitat has been designated within the Study Area for Chinook, Coho, and Pink salmon under the Magnuson-Stevens Act (Map 7). (Pacific Fishery Management Council, 2014b).

Ocean conditions have been used to forecast returns of Chinook and Coho salmon, including the Pacific Decadal Oscillation, sea surface temperature anomalies, coastal upwelling, spring transition date, and copepod biomass anomalies (Andrews et al., 2015; Burke et al., 2013; Peterson et al., 2015). Salmon recovery management measures in Washington include hatchery programs, habitat improvement, and fisheries management (Washington State Department of Fish and Wildlife, 2008).

Green sturgeon are believed to spend the majority of their lives in nearshore oceanic waters, bays, and estuaries. The southern distinct population (SDP) of green spawns only in the Sacramento River, CA and is listed under the Endangered Species Act as threatened (Adams et al., 2007). Adult sturgeon from the SDP enter Willapa Bay during the late spring and early summer months and feed on burrowing shrimp (*Neotrypaea californiensis*) (Dumbauld, Holden, & Langness, 2008; Moser & Lindley, 2007). It is conjectured that they also feed on mollusks, and amphipods, and even small fish (NOAA Fisheries, 2014b). Green sturgeon ESA critical habitat is within much of the Study Area occurring along the entire coast, including Grays Harbor and Willapa Bay (Map 7) (NOAA Fisheries, 2014b).

Pacific eulachon (aka "candlefish" or "smelt") are small anadromous fish that typically spend three to five years in saltwater before returning to freshwater to spawn. While in the ocean, eulachon typically spend their time in nearshore waters and up to 1,000 feet (300 meters). Eulachon populations declined dramatically in the past 20 years, and the fish was listed as Threatened under the ESA in 2008 (NOAA Fisheries, 2014a). The MSP Study Area is important habitat for eulachon, and eulachon ESA critical habitat is directly adjacent to the Study Area (Map 7). Eulachon are an important cultural fishery for many tribes in Washington.

Table 2.1-2. Anadromous fish species occurring within the MSP Study Area. Source: (Washington State Department of Fish and Wildlife, 2015d).[11]

Common name	Species name	Federal status	State status
Chinook salmon	*Oncorhynchus tshawytscha*	Threatened/Endangered	State Candidate
Chum salmon	*Oncorhynchus keta*	Threatened	State Candidate
Coho salmon	*Oncorhynchus kisutch*	Threatened	none
Pink salmon	*Oncorhynchus gorbuscha*	none	none
Sockeye salmon	*Oncorhynchus nerka*	Threatened/Endangered	State Candidate
Steelhead	*Oncorhynchus mykiss*	Threatened	State Candidate/none
Coastal cutthroat trout	*Oncorhynchus clarki*	none	none
Pacific eulachon	*Thaleichthys pacificus*	Threatened	State Candidate
Green sturgeon	*Acipenser medirostris*	Threatened	none
White sturgeon	*Acipenser transmontanus*	none	none
Pacific lamprey	*Entosphenus tridentatus*	Species of concern	State monitored
American shad	*Alosa sapidissima*	none	none

Marine mammals

At least 29 species of marine mammals inhabit or transit through the MSP Study Area at some point in their lives. Species include baleen and toothed whales, seals and sea lions, and sea otters. Many marine mammals are top predators within the ecosystem, while some large baleen whales are primarily filter or bottom feeders (e.g. Humpback and Gray whales). Diets vary from krill, invertebrates, forage fish, salmon, other fishes, and even other marine mammals. About 20,000 Gray whales migrate through the Study Area, with the abundance of Gray whales at any time influenced by environmental variability within the Arctic feeding grounds and the timing of migration (Olympic Coast National Marine Sanctuary, 2011). In southern Washington, a visual survey of marine mammals was conducted over eight trips between July 2008 and June 2009 in the area between Grays Harbor, the Quinault Canyon, and Grays Canyon. This survey found the Harbor porpoise to be the most commonly sighted marine mammals in nearshore waters, and Dall's porpoise was the mostly commonly sighted marine mammal in

[11] Salmon are listed and managed as ESU's, some species with several ESU's. Therefore, at the species level, there may be multiple and differing ESA listings.

offshore waters (Oleson & Hildebrand, 2012). A visual survey in June 2008 within the OCNMS found that humpback whales were the most commonly sighted cetacean (Oleson & Hildebrand, 2012).

Orcas (aka killer whales) are also found in the MSP Study Area.[12] Orcas are divided into four populations based on ecology, genetics, diet, behavior, and social interactions. Three populations are described as "resident" orcas: northern, southern, and offshore. Resident orcas are fish-eating, with northern and southern populations mainly feeding on salmonids and occasionally bottom fish. Transient orcas in Washington waters are mammal-eating, preying mainly upon harbor seals. All four populations of orcas occur within the MSP Study Area, although their distribution, abundance, and temporal use of the area varies by population. The distribution of the populations is best known during summer when the most monitoring has occurred. During this time, the northern resident population has a core range in inshore British Columbia, the southern residents population is centered in the inshore waters near the border of Washington and British Columbia, and the offshore population is generally found on the continental shelf from southern California to the Aleutian Islands (Lance, Calambokidis, Baird, & Steiger, 2011). Population sizes are well established for northern and southern resident orcas, with less precision around population estimates of offshore resident and transient orcas. Southern resident orcas are listed as Endangered under the ESA, and all killer whales are listed as Endangered in the State of Washington (Table 2.1-3) (Lance et al., 2011).

The National Centers for Coastal Ocean Science (NCCOS) developed relative density models for four cetaceans to inform the likely distributions of these animals for the MSP. Species were chosen by Ecology and WDFW because they were species of management concern. The maps were created by using associative models linking at-sea mammal observations with environmental covariates. Maps were produced for Dall's porpoise (*Phocoenoides dalli*), harbor porpoise (*Phocoena phocoena*), gray whale (*Eschrichtius robustus*), and humpback whale (*Megaptera novaeangliae*). These maps do not include cetacean use of the estuaries. Cetaceans, especially gray whales and harbor porpoises, are known to use the estuaries. More details on the NCCOS modeling effort and available maps are in Section 3: Spatial Analyses.

DNR worked to identify ecologically important areas (EIAs). EIAs are defined as areas where animals, especially those of interest to fisheries and wildlife management, are shown through existing data to use the MSP Study Area the most. More information about the EIA analysis process and additional maps are available in Section 3: Spatial Analyses. An EIA hotspot map was created for the marine mammal subsector (Map 8) and for humpback whales (Map 9).

Harbor and elephant seals, and California and Steller sea lions aggregate and haul out on rocky islands, coastal areas, and estuaries of the MSP Study Area (Map 10). Harbor seals and California sea lions use the coastal estuaries frequently. Northern fur seals also transit through and forage within the MSP Study Area) (Lance et al., 2011). Similar to cetaceans, NCCOS developed relative density models for the harbor seal (*Phoca vitulina*) and Steller sea lion (*Eumetopias jubatus*) to inform the likely distributions of these animals in the MSP Study Area (excluding their use of the estuaries) (See Part 3).

A population of sea otters also occurs in the Study Area, favoring rocky habitats and kelp forests along the Olympic Peninsula coast from Destruction Island northward to Tatoosh Island (Map 10). Extirpated by fur trade hunters in 1911, sea otters were reintroduced to the outer coast in 1969 and 1970 (Lance et al., 2011). The population in 2015 was approximately 1,394 animals (Jeffries, Lynch, & Thomas, 2016). Population growth in the state has been slower than anticipated in the past few years,

[12] Orcas are found in all oceans and seas of the world, with their density being greatest in colder waters within 800 km of major continents. Off the west coast of North America they are found in relatively high density in near-shore waters from Alaska to central California (Lance, Calambokidis, Baird, & Steiger, 2011).

possibly because the sea otter population has reached carrying capacity within its current range, and has not yet expanded to other anticipated areas (Lance, Richardson, & Allen, 2004). Sea otters are a keystone species that help maintain kelp forest habitat structure by predating on sea urchins (Andrews et al., 2013; Olympic Coast National Marine Sanctuary, 2011).

Ten marine mammal species listed under the federal ESA or Washington species of concern list occur within the MSP Study Area (Table 2.1-3). Stressors for marine mammals include collisions with and other boat interactions (e.g. noise), entanglement in fishing gear and marine debris, contaminants, oil spills, alterations in habitat and prey, and oceanographic conditions (Andrews et al., 2013; Olympic Coast National Marine Sanctuary, 2011). All marine mammals, whether listed under the ESA or state species of concern, are currently protected by the Marine Mammal Protection Act (16.U.S.C. §§1631 et seq).[13]

Table 2.1-3. Marine mammals on the federal or state species of concern lists within the MSP Study Area. Source (Washington State Department of Fish and Wildlife, 2015d).

Common name	Species name	Federal status	State status
Blue whale	*Balaenoptera musculus*	Endangered	State Endangered
Fin whale	*Balaenoptera physalus*	Endangered	State Endangered
Gray whale	*Eschrichtius robustus*	None	State Sensitive
Harbor porpoise	*Phocoena*	None	State Candidate
Humpback whale	*Megaptera novaeangliae*	Endangered	Endangered
Killer whale	*Orcinus orca*	Endangered[14]	Endangered[15]
North Pacific right whale	*Eubalaena japonica*	Endangered	Endangered
Sea otter	*Enhydra lutris*	Species of Concern	Endangered
Sei whale	*Balaenoptera borealis*	Endangered	Endangered
Sperm whale	*Physeter macrocephalus*	Endangered	Endangered
Steller sea lion	*Eumetopias jubatus*	Species of Concern	None

[13] There are some exceptions to the Marine Mammal Protection Act, including small takes of incidental harvest such as harvest by Alaskan natives.

[14] This listing is for the Southern Resident Orca population, the other three populations (northern, offshore, and transient) are not listed under the ESA.

[15] The State of Washington lists all Killer Whales in the state as Endangered.

Birds

Numerous bird species use and transit through the MSP Study Area. Many species of birds, including seabirds, raptors, marshbirds, waterbirds, and shorebirds, forage and nest in sea stacks, rocky offshore islands, cliffs, bluffs, dunes, marshlands, estuaries, tidal flats, coastal beaches, and old-growth forests. Seabird and shorebird populations occur throughout the outer coast of Washington, with the majority located along the west coast of the Olympic Peninsula (Map 11). Washington is also along the Pacific Flyway, a migratory pathway for millions of waterbirds, shorebirds, and raptors. Some seabird species migrate thousands of miles to forage in MSP offshore waters, such as albatross and shearwaters (Kaplan, Beegle-Krause, French McCay, Copping, & Geerlofs, 2010; Olympic Coast National Marine Sanctuary, 2011). Estuaries are also crucial habitat for several resident and migratory bird species. Five National Wildlife Refuges have been established in or directly adjacent to the MSP Study Area (Map 1) to protect land-based resources where large concentrations of birds occur and where seabirds nest.

DNR developed EIA maps for some of bird species, additional information and maps can be found in Section 3: Spatial Analyses.

Marshbirds

The term marshbird broadly encompasses birds that feed, nest, or otherwise utilize tidal or freshwater marshes (includes herons, egrets, rails, and passerines). They do not swim, rather forage on sandy beaches, marshes, and other coastal areas. Examples of marshbirds in Washington include the great blue heron (*Ardea Herodias*), marsh wren (*Cistothorus palustris*), great egret (*Ardea alba*), and American bittern (*Botaurus lentiginosus*). Marshbirds are associated with estuaries such as Grays Harbor and Willapa Bay. Marshbirds are sensitive to human disturbance and nesting sites can be abandoned due to land development, wetland loss, logging, and human intrusions (Kaplan et al., 2010; United States Department of the Navy, 2015).

Ducks and geese

Ducks and geese (Family Anatidae) are generally present along protected shores, bays, and estuaries. Large numbers occur during the winter, and the birds migrate north or east to summer breeding grounds. Most species of ducks and geese feed by diving, dabbling, or foraging from the surface and have diverse diets ranging from mollusks and fish eggs to vegetation. Species include black brant (*Branta bernicla*), greater scaup (*Aythya marila*), green-winged teal (*Anas crecca*), tundra swan (*Cygnus columbianus*), bufflehead (*Bucephala albeola*), and others. Willapa Bay is an important stopover for wintering black brant. The Columbia River estuary provides habitat for swans and wintering ducks. Harlequin ducks (*Histrionicus histrionicus*) winter along the Pacific Coast and forage for crustaceans, mollusks, and aquatic insects within rocky substrate and kelp beds (Kaplan et al., 2010; United States Department of the Navy, 2015).

Shorebirds

Shorebirds include species such as sandpipers, plovers, oystercatchers, avocets, and stilts. Shorebirds can migrate long distances (up to thousands of miles) between wintering and breeding grounds. Coastal estuaries and wetlands are used during the migratory stopovers to rest, feed, and replenish their fat reserves needed for the continuing migration primarily to the high arctic where they nest. Shorebirds can congregate in high concentrations, sometime numbering in the millions. Shorebirds mainly feed on invertebrates present in shallow waters and associated wetlands, beaches, mudflats, and other tidelands. Grays Harbor and Willapa Bay represent important stopover sites for many species, such as dunlin (*Calidris alpina*). At the same time, there are a couple of species that breed locally. The

Western snowy plover (*Charadrius alexandrines nivosus*) breeds on sandy beaches adjacent to the MSP Study Area in Grays Harbor and Pacific Counties. Black oystercatchers (*Haematopus bachmani*) also breed adjacent to and within the MSP Study Area along the rocky coast and offshore rocks and islands. Coastal development and human activities have degraded shorebird stopover and colony habitat (Kaplan et al., 2010; Olympic Coast National Marine Sanctuary, 2011; United States Department of the Navy, 2015).

Seabirds

Several species of seabirds (albatrosses, petrels, shearwaters, and alcids) occur within the MSP Study Area. Examples include murres, puffins, albatrosses, fulmars, shearwaters, gulls, murrelets, cormorants, terns, and others. Seabird use of the area varies seasonally and influenced by physical and biological processes. Some species travel vast distances across the globe to forage in MSP waters during summer, such as the sooty shearwater (*Puffinus griseus*), which breeds in New Zealand. Several species of seabirds breed on coastal islands within the Study Area, such as Tatoosh and Destruction Islands. Some seabirds forage far offshore over the continental shelf and oceanic waters, while others, such as the common murre and marbled murrelet forage in fairly nearshore environments. Diets vary by species, but mainly consist of fishes and invertebrates. Seabird abundance and reproductive success is influenced by short-term and long-term oceanographic conditions, oil spills, disturbance of breeding colonies, fisheries bycatch, and predators such as raptors (Kaplan et al., 2010; Olympic Coast National Marine Sanctuary, 2011; United States Department of the Navy, 2015).

Unlike most seabirds that nest on offshore islands and rocks, marbled murrelets nest in old growth forests, up to 55 miles inland in Washington. Marbled murrelets are listed as threatened on the federal and state species lists and are subject to many pressures. Reduction of appropriate nesting habitat is one of the primary pressures for these birds. Marbled murrelets are monitored annually in Washington (Washington State Department of Fish and Wildlife, 2013).

Seabirds are often considered indicators for ocean conditions because they forage across multiple habitats and trophic levels. Because of their behavior of life histories, seabirds can be difficult to monitor. Some species are monitored as indicators for other seabird populations. The National Centers for Coastal Ocean Science (NCCOS) developed models to predict relative density (using environmental covariates) from survey data to inform the MSP. Species were chosen to represent different habitat uses that ranged from nearshore species like the marbled murrelet to pelagic species like the northern fulmar and black-footed albatross. Species that are locally rare or declining were also included (e.g., pink-footed shearwater and tufted puffin). These maps do not include seabird use of the estuaries because surveys largely did not occur in the estuaries. Maps were produced for marbled murrelet (*Brachyramphus marmoratus*), tufted puffin (*Fratercula cirrhata*), common murre (*Uria aalge*), black-footed albatross (*Phoebastria nigripes*), northern fulmar (*Fulmarus glacialis*), pink-footed shearwater (*Puffinus creatopus*), and sooty shearwater (*Puffinus griseus*) (Menza, Battista, & Dorfman, 2013). See Section 3: Spatial Analyses for more information and maps.

The EIA hotspot map for the Seabirds subsector is Map 12.

Raptors

A few species of raptors forage within and adjacent to the MSP Study Area, including bald eagles (*Haliaeetus leucocephalus*) and peregrine falcons (*Falco peregrinus*). Bald eagles and peregrine falcons nest along the outer coast; the eagles prey upon seabirds, waterfowl, and salmon, and the falcons prey upon shorebirds, seabirds, ducks, and other birds (Washington State Department of Fish and Wildlife, 2013). These birds also prey upon common murres and other surface nesting birds during the breeding season (Olympic Coast National Marine Sanctuary, 2011).

Birds with Special Protection

Several species of birds occurring adjacent to and within the Study Area have federal or state special protection (Table 2.1-4). Seabirds, raptors, shorebirds, waterbirds, marshbirds, and terrestrial birds are included in this list. A terrestrial bird, the streaked horned lark, nests and forages on sandy beaches along the southern outer coast and islands of the lower Columbia River (See Section 3: Spatial Analyses for the EIA map) (Washington State Department of Fish and Wildlife, 2013). Common reasons for bird population declines include oceanographic factors (e.g. El Niño), which can affect their food source, habitat degradation, pollution and oil spills, and predation (Kaplan et al., 2010; Olympic Coast National Marine Sanctuary, 2011). National Wildlife Refuges, Olympic Coast National Marine Sanctuary, WDFW, and WDNR implement management measures to help protect and recover populations of listed species in Washington.

Table 2.1-4. Birds on the federal or state species of concern lists occurring within or directly adjacent to the MSP Study Area. Source: (Washington State Department of Fish and Wildlife, 2015d)

Common name	Species name	Federal status	State status
Bald eagle	*Haliaeetus leucocephalus*	Species of Concern	State Sensitive
Brand's cormorant	*Phalacrocorax penicillatus*	None	State Candidate
Brown pelican	*Pelecanus occidentalis*	Species of Concern	State Endangered
Cassin's auklet	*Ptychoramphus aleuticus*	None	State Candidate
Clark's grebe	*Aechmophorus clarkii*	None	State Candidate
Common loon	*Gavia immer*	None	State Sensitive
Common murre	*Uria aalge*	None	State Candidate
Marbled murrelet	*Brachyramphus marmoratus*	Threatened	State Threatened
Peregrine falcon	*Falco peregrinus*	Species of Concern	State Sensitive
Purple martin	*Progne subis*	None	State Candidate
Sandhill crane	*Grus canadensis*	None	State Endangered
Short-tailed albatross	*Phoebastria albatros*	Endangered	State Candidate
Snowy plover	*Charadrius nivosus*	Threatened	State Endangered

Streaked horned lark	*Eremophila alpestris strigata*	Threatened	State Endangered
Tufted puffin	*Fratercula cirrhata*	None	State Endangered
Western grebe	*Aechmophorus occidentalis*	None	State Candidate

Sea turtles

Three species of sea turtles occur within the MSP Study Area: leatherback, loggerhead, and green sea turtles. All three of these turtles are listed under the federal ESA and Washington State species of concern (Table 2.1-5). These sea turtles feed and migrate through MSP waters; no nesting sites occur within Washington State (they nest in tropical regions). The leatherback sea turtle is the only sea turtle regularly found in Washington waters. Leatherbacks feed primarily on jellyfish, which are found in the upper part of the water column. Leatherbacks are found in MSP waters during the summer and fall, especially in the Columbia River Plume and in other areas where the oceanographic conditions tend to aggregate jellyfish (Washington State Department of Fish and Wildlife, 2013).

Designated critical habitat for leatherback sea turtles occurs throughout the MSP Study Area. A primary stressor within the Study Area is pollution, particularly plastic bags which leatherbacks mistake for jellyfish and ingest. Entanglement in fishing gear can also be a stressor, but the drift gillnet and pelagic longline fishing gears that primarily affect leatherbacks are no longer permitted in the Study Area and therefore the risk of entanglement is now quite low (Washington State Department of Fish and Wildlife, 2013). Sightings of loggerhead and green sea turtles are rarely recorded off the Washington coast. Only four strandings of green sea turtles and no strandings of loggerheads were recorded between 2002 and 2012 (Washington State Department of Fish and Wildlife, 2013).

Table 2.1-5. Sea turtles within the MSP Study Area and their federal and state species of concern status. Source: (Washington State Department of Fish and Wildlife, 2015d).

Common name	Species name	Federal status	State status
Green sea turtle	*Chelonia mydas*	Threatened	State Threatened
Leatherback sea turtle	*Dermochelys coriacea*	Endangered	State Endangered
Loggerhead sea turtle	*Caretta caretta*	Endangered	State Threatened

Stressors

The MSP Study Area is subject to many stressors from human activities (aka anthropogenic stressors). These stressors may harm wildlife, alter water quality, and degrade habitat. This section presents summaries of some of the key anthropogenic stressors in the MSP Study Area: invasive species, oil spills, marine debris, vessel discharge, fishing pressures including habitat modification related to bottom gear, shoreline development, human disturbance and trampling, ocean noise, and vessel strikes.[16] While this is not meant to be an exhaustive discussion of various human stressors to ocean ecology, these topics are presented here to acknowledge the major identified impacts that Washington's ocean environment currently faces.

Invasive species

Invasive species are non-native organisms that harm or pose a risk of harming the state's environmental, economic, or human resources.[17] Invasive species including diseases, parasites, plants, invertebrates, and vertebrates occur along the Washington coast in a variety of habitats. Invasive species can be intentionally or unintentionally introduced through a variety of ways, including ballast water discharge, use of organisms for packing material, fouling on aquaculture shipments, aquarium trade with subsequent release into the environment, recreational boating, range expansion due to climate change, and floating debris (e.g. biofouling on debris arriving from 2011 Japanese tsunami) (Andrews et al., 2015, 2013; Office of National Marine Sanctuaries, 2008; Skewgar & Pearson, 2011).

Invasive species can have a profound impact on the habitat, trophic interactions, and ecology of an area, which can also lead to significant social and economic burdens, particularly for recovery of species such as salmon, and fishery and aquaculture industries (Office of National Marine Sanctuaries, 2008). Statewide, there are 94 known marine invasive species recorded, 59 of which occur on Washington's Pacific coast (Davidson, Zabin, Ashton, & Ruiz, 2014). The MSP Study Area has been subject to impacts from invasive species, with some of the more well-known invasions occurring in the coastal estuaries. Examples include Atlantic cordgrass (*Spartina alterniflora and S. densiflora*), Japanese eelgrass (*Zostera japonica*), and European green crab (*Carcinus maenus*). The brown alga (*Sargassum muticum*) is an example of an invasive species that has been found in rocky shores and mixed substrate sites on the Pacific Ocean coast, yet little is currently known on its impacts to native species or other algae in WA (Skewgar & Pearson, 2011).

The prevention and control of invasive species is a complex task and depends upon the vector as well as effective treatments for each species. Resource managers consider prevention to be the best and most cost-effective way to manage invasive species (Cusack, Harte, & Chan, 2009). Recreational vessel cleaning, ballast water management, vessel inspections, biofouling management, and prohibiting the release of non-native species are some of the primary ways Washington attempts to prevent the introduction and spread of aquatic invasive species (Washington State Department of Fish and Wildlife, 2015a).

In the cases of established, invasive populations, Washington may take direct action to control populations and prevent further spread of species that are significant threats to native habitat and/or natural resource industries. The types of management applied in these situations, ranging from physical removal to application of herbicide and pesticide chemicals, depends on multiple factors including the species, extent of establishment, degree of containment possible, and urgency of the threat to Washington's environmental, economic, or human resources. For example, management of invasive species on Japanese tsunami marine debris was primarily by physical removal (Washington State Department of Fish and Wildlife, 2015c); whereas in Willapa Bay and Grays Harbor, herbicides were ultimately the best management tool used to control invasive Atlantic cordgrass (Washington State Department of Agriculture, 2015).

[16] Climate change is discussed in Part 2.11 of the MSP

[17] Management of native species which become harmful is handled by the State differently, and are not discussed here.

Multiple agencies are involved with decisions related to invasive species control. The Washington Invasive Species Council coordinates among state agencies to support a comprehensive strategy for making effective investments to protect Washington from invasive species (Washington Invasive Species Council, 2014). Washington also has specific programs related to the prevention and control of invasive species.[18] These programs focus on various aspects of outreach, education, reporting, prevention, enforcement, and treatment related to invasive species.

Invasive species will continue to be a stressor into the future with a significant risk of impact within the MSP Study Area and Washington State. It is possible that potential new uses, such as marine renewable energy, offshore aquaculture, or other activities could become vectors for invasive species.

Oil spills

Oil is routinely transported through the MSP Study Area on many types of vessels as fuel, lubricating oil, hydraulic fluid, and as a byproduct from fish processing. Crude oil and refined products are also carried as cargo on tankers and oil barges. Vessels of all types transit through the study area, including vessels entering and exiting the Strait of Juan de Fuca, Grays Harbor, and the Columbia River. Larger vessels, including tankers and oil barges typically travel 25 to 50 nautical miles off the coast (City of Hoquiam & Washington State Department of Ecology, 2015a, 2015b; Washington State Department of Ecology et al., 2015).

Oil spills in the marine environment can negatively affect water quality and directly injure plants, animals, and habitat. An oil spill may also negatively impact human activities and interests such as recreation, cultural resources, tribal resources, human health, fisheries, and aquaculture. The extent of impact to these resources depends on the location and volume of the spill and type of oil; a large oil spill would likely have a significant negative impact on many or all of the above listed resources (City of Hoquiam & Washington State Department of Ecology, 2015a, 2015b). While rare, large oil spills have occurred on the Washington Coast, including the 1988 *Nestucca* barge spill (231,000 gallons of fuel oil) off Grays Harbor and the 1991 *Tenyo Maru* fishing vessel spill (100,000 gallons of diesel fuel) off the north end of the Pacific Coast (Office of National Marine Sanctuaries, 2008). Smaller spills occur more frequently than large spills, and sources for spills reported off the coast between 2011 and 2015 include fishing vessels, recreational vessels, and a tank vessel (Washington State Department of Ecology, 2015).

The Washington Department of Ecology has a Spills Program that seeks to protect Washington's environment, public health and safety through comprehensive spill prevention, preparedness, and response. When a spill does occur, the program responds in a rapid, aggressive, and well-coordinated manner. Day-to-day program work includes prevention inspections (vessels, oil transfers, and facilities) contingency planning, geographic response plan development, and worst case drills and exercises with industry. Response drills and exercises ensures the major parties, including industry, are able to respond in a unified manner through an Incident Command System, as required by industry contingency plans and the State Area Plan[19]. Recent legislation has directed the Spills program to look at the risks imposed

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[18] Some examples include including the Washington State Aquatic Invasive Species Prevention and Enforcement Program co-administered by WDFW and Washington State Patrol, the Washington State Noxious Weed Control Board that advises the WSDA on noxious weed control, the Washington Department of Ecology's Aquatic Weeds Program, and others.

[19] The state has adopted the Northwest Area Contingency Plan (NWACP) as the state's Oil and Hazardous Substance Spill Prevention and Response Plan, which applies to the activities of all state and local agencies involved in managing oil and hazardous substance spills. Ecology is the state's lead agency to oversee prevention, abatement, response, containment and cleanup efforts with regard to an oil or hazardous substance spill to waters of the state. Ecology coordinates with federal, state, and tribal members of the Region 10 Regional Response Team

by the changing energy transportation picture and develop countering measures, geographic response plan expansion, improvements in response equipment caches, and rail contingency planning.

Changes in oil supply in the U.S. and Canada are likely to influence the movement of crude oil in Washington State to refineries in the Puget Sound area and also in Vancouver, British Columbia. Alaskan crude oil, transported by tankers and pipelines, has been decreasing and is expected to continue to decline. However, increased supply of crude oil from the Bakken formation in North Dakota has substantially increased the amount of crude oil entering the state by train and has stimulated project proposals for updating existing refineries and for crude oil storage and transfer facilities in Grays Harbor and along the Columbia River (Washington State Department of Ecology et al., 2015). Heavier tar sands crude oil from Canada may also be transported in Washington by existing and proposed pipeline facilities.

There are currently two proposed projects in Grays Harbor to increase crude-by-rail capacity by adding new offload stations and storage tanks. If these proposed projects were to move forward, there would be an increased risk of oil spills in Grays Harbor due to the increased volume of oil transported and the increased frequency of vessel traffic. A large oil spill in Grays Harbor could also affect the outer coast of Washington. Through Environmental Impacts Statements (EISs) for the proposals, the Contanda (formerly Westway Terminal Company) Terminal expansion and the Renewable Energy Group (formerly Imperium Renewables Inc.) Terminal expansion, the City of Hoquiam and the Washington Department of Ecology have identified potential significant impacts to the environment and have identified mitigation measures to avoid and minimize some impacts. Ecology and the City of Hoquiam have also identified that while the likelihood of a large spill is low, it would likely result in unavoidable and significant adverse environmental impacts and that no mitigation measures would completely eliminate the possibility of a large spill or the adverse consequences of such an incident (City of Hoquiam & Washington State Department of Ecology, 2015a, 2015b; Washington State Department of Ecology et al., 2015).

In addition, projects have been proposed along the Washington side of the Columbia River that would increase crude-by-rail capacity, build new storage tanks for the storage and marine transport of oil and build a new refinery that could handle crude oil. Similar to Grays Harbor, if these proposed projects were to move forward, there would be an increased risk of oil spills in the Columbia River due to the increased volume of oil transported, risk due to transfer of oil between rail cars, storage facilities, and/or vessels, and the increased frequency of vessel traffic.

Olympic Coast National Marine Sanctuary (OCNMS) recognizes the potential accidental release of oil into the marine environment as the greatest threat to sanctuary resources and qualities. Prevention of spills is one of OCNMS' highest priorities, along with preparation and response to spills. OCNMS initially promoted and currently monitors compliance with the Area to be Avoided.[20] The ATBA is a voluntary measure that routes large vessels offshore and decreases risk of vessel groundings and spills reaching the shore with greater than 95% compliance (Olympic Coast National Marine Sanctuary, 2011). Oil spill response and prevention is also a key concern for tribes and several federal and state agencies.

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and the Northwest Area Committee to prevent and respond to oil and hazardous substance spills. For more information on the Region 10 Regional Response Team and NWACP, please go to http://www.rrt10nwac.com/Default.aspx

[20] The Area to be Avoided is a boundary where all vessels above 400 gross tons and all ships and barges carrying petroleum and hazardous materials in bulk as cargo or cargo residue are advised to maintain a 25 mile buffer from the coast. The ATBA compliance rate has consistently been very high and was estimated to be over 97% in 2014 (Olympic Coast National Marine Sanctuary, 2015).

Representatives from these governments and agencies participated in the Region 10 Regional Response team and Northwest Area Committee activities focused on oil spill prevention, planning, and response.

Marine debris

Marine debris is known to have both ecological and economic impacts worldwide, and is a notable stressor in the MSP Study Area. One of the most visible impacts of marine debris is wildlife entanglement in debris, which can lead to injury, illness, and death. Ingestion of marine debris is also a harmful impact to wildlife. Sea turtles, seabirds, and marine mammals have been known to ingest marine debris, often mistaking debris items for food. Economic impacts include negative impacts on tourism, cost of cleanup, degradation of beaches and habitat, vessel damage, and navigation hazards. Marine debris can also be vectors for non-native species, which can have both ecological and economic impacts (NOAA Office of Response and Restoration, 2015).

Marine debris is present along the entire Washington coast of the MSP Study Area and comes from a variety of sources. Human trash from direct beach recreation activities, upland sources, as well as trash generated from locations around the Pacific Rim is found on Washington's beaches. Debris from fishing, aquaculture, and shipping activities is also found on the shore. Plastics make up approximately 92% of the debris on outer coast beaches in Washington. Debris from the Japanese tsunami has also been arriving on Washington's ocean beaches since the event in 2011. Tsunami debris has included a variety of objects such as construction materials, boats, a large dock, and some hazardous materials, such as propane tanks. Non-native species have often been found attached to this debris and required removal. Tsunami debris has been intermittent and widely scattered, sometimes in significant quantities, but by 2017 contributes very little to shoreline debris loading. Efforts have been coordinated by NOAA, the State, and others to safely remove tsunami debris. NOAA continues to work with other federal, state, and local partners to monitor and remove tsunami debris (Barnea, 2015; NOAA Office of Response and Restoration, 2015).

Several marine debris volunteer cleanup events occur yearly on beaches in the Study Area. Currently, the majority of these cleanups are coordinated through the Washington CoastSavers with many participating nonprofit, business, and government organizations. While CoastSavers has been coordinating cleanup events since 2007, community groups have been holding cleanup events on the Washington coast since as early as 1971. Significant annual marine debris collection events include the Washington Coast Cleanup held in April near Earth Day, the International Coast Cleanup held in late summer, and the July 5th cleanup held on several southern beaches to clean up trash and fireworks from 4th of July celebrations. The amount of marine debris collected from these events can be quite large. CoastSavers estimates over 320 tons of marine debris have been collected during the April Washington Coast Cleanup events from 2000-2012, ranging from 15 to 40 tons collected per year. The July 4th, 2015 cleanup from Moclips to Long Beach collected 115 tons of debris (Washington CoastSavers, 2015).

Efforts are also underway to remove derelict fishing gear from Washington's ocean. Derelict (abandoned or lost) gear can continue to catch fish and harm wildlife (aka ghost fishing). Tribes, the State (particularly DNR's Restoration Program and Derelict Vessel Program), and The Nature Conservancy are working to remove lost crab pots off the Washington coast, which benefits the crab, the fishermen, and the environment (Miller, 2015).

While cleanup remains an important part of addressing marine debris as a stressor for Washington's beaches and waters, programs also focus on prevention education and outreach to reduce the amount of marine debris on the beach and in the ocean. Potential new ocean uses may generate new sources of marine debris, unless their gear and waste activities are effectively managed to prevent entry into the environment.

Vessel discharges

All types of vessels generate wastewater. The type and amount of wastewater generated depends on the vessel, passenger load, vessel size, function, and condition. Examples of wastewater include sewage, graywater (e.g. water from showers, dishwashing, etc.), bilgewater (a mixture of engine water, cleaning agents, and many other sources), and ballast water (i.e. water for stability). Sewage can be directed to a marine sanitation device to either treat the materials prior to discharge or to hold it until it can be pumped to a land based facility. The amount of wastewater discharged into the MSP Study Area is unknown, however some estimations have been performed for the OCNMS area. In 2009, cruise ships (i.e. passenger vessels >1,600 GT with an average of about 3,000 passengers) were estimated to contribute approximately 63% of all sewage discharges and approximately 75% of all graywater discharges within OCNMS waters, making cruise ships the largest potential contributor of vessel discharges (Olympic Coast National Marine Sanctuary, 2011).[21] OCNMS regulations implemented in 2011 now prohibit all cruise ship wastewater discharges within sanctuary waters (15 CR §922.152).

While the OCNMS water quality condition was rated as “good” in the 2008 OCNMS condition report (Office of National Marine Sanctuaries, 2008), there are concerns surrounding what water quality impacts vessel discharges could have within ocean waters. Vessel discharges could contain pathogens, elevated nutrient contents, or toxic substances which may harm wildlife or human health. Regulatory and voluntary measures for vessel discharge within State, OCNMS, and federal waters are currently in place to address many types of vessel discharges. Regulations and agreements are complex, and depend upon the vessel type, vessel size, discharge type, location of discharge, and other factors. One example is that in the U.S., all non-recreational vessels 79 feet or greater in length may not discharge substances to marine waters without a National Pollutant Discharge Elimination System Vessel General Permit (VGP)[22]. The VGP contains restrictions on the discharge to OCNMS waters, and Flattery Rocks and Willapa National Wildlife Refuge’s waters in the MSP Study Area, as well as several other waters within the state[23].

Vessel discharges must meet state water quality standards. However, many onboard treatment systems do not meet these standards, and so vessels are guided to onshore pumpout facilities or to withhold discharges until outside of state waters. A memorandum of understanding between the North West & Canada Cruise Association, Port of Seattle, and the Washington Department of Ecology restricting sewage and graywater discharge in state waters (3 nm) and OCNMS is in place for cruise ships not utilizing advanced wastewater treatment systems (Olympic Coast National Marine Sanctuary, 2011).

Washington State agencies, OCNMS, the Environmental Protection Agency, and vessel users will continue to work together to address vessel wastewater discharge to protect the marine ecosystem and human health.

Fishing pressures and bottom gear

The MSP Study Area is important for commercial, tribal, and recreational fishing. Several fisheries occur within the MSP Study Area and are managed by the Pacific Fisheries Management Council,

[21] This assessment did not include estimates from offshore fish processors.

[22] Certain discharge and vessel types are not covered or are exempt from the general permit. For more information please see http://www.ecy.wa.gov/programs/wq/permits/VGP/index.html

[23] For a list of Washington water bodies affected by the Vessel General Permit, please see Appendix G of the VGP available at http://www.epa.gov/npdes/vessels-incidental-discharge-permitting-3

Washington State, and treaty tribes.[24] The MSP Study Area has a long history of fishing activity, with some periods of unsustainable and habitat damaging practices. One of the most prominent examples is the use of bottom trawl gear for groundfish fishing. Bottom trawl gear can directly damage seafloor habitat, particularly hard bottom habitats and areas with biogenic habitat such as deep sea coral reefs and sponges. These biogenic habitats are slow growing, and may take decades to recover. While the exact extent of biogenic and hard bottom habitats within the MSP Study Area is unknown, the extensive bottom trawl fishing spanning several decades likely damaged some of this habitat (Office of National Marine Sanctuaries, 2008).

Governments and fishermen are working together to sustainably utilize the valuable fishery resources within the area. For example, the groundfish fishery has been rationalized and reduced through a buyback program, and groundfish and rockfish conservation closure areas have been created as part of fishery management. Gear restrictions and closure areas to non-tribal commercial fishermen are expected to aid in the recovery of depleted groundfish stocks as well as to allow the critical, slow growing biogenic seafloor habitat to recover (Office of National Marine Sanctuaries, 2008).

Shoreline development

Shoreline development such as jetties, groins, and residential structures near beaches can degrade habitat through changes to sediment supply and loss of beach habitat. These changes represent a potential increasing stressor to the natural system as the coastal population continues to grow. The northern half of the MSP Study Area coast (Clallam and Jefferson Counties) is largely undeveloped and new coastal development will likely remain limited in the foreseeable future. The southern MSP Study Area coast (Grays Harbor and Pacific Counties) has a higher population with more cities and towns along the shoreline. The current primary driver for development on southern beaches is construction for vacation and retirement homes; however, development pressure is relatively low compared to other marine shorelines in the State (e.g. Puget Sound). Through Washington's Shoreline Management Act, local governments and the Washington State Department of Ecology have regulations and standards for shoreline development in order to protect habitat, facilitate water dependent and preferred uses, and provide public access (RCW 90.58.020). Local governments and the State will continue to evaluate coastal development projects to allow for coastal population growth and use of shoreline resources while protecting the marine environment.

Human disturbance and trampling

Human visitors to the coast can have varying impacts on shore habitats and wildlife, depending on the habitat types, types of activities, and intensity of use. Many of Washington's southern beaches are visited frequently by beach combers, razor clammers, beach drivers, and other users. Sandy beaches are relatively resilient to these types of human activities, although there are potential impacts to birds through disturbance of nesting and foraging habitats (Skewgar & Pearson, 2011).

Harvest and trampling of intertidal organisms on rocky shores can harm these habitats. Non-tribal harvest from rocky areas is generally focused on gooseneck barnacles and mussels. WDFW, the tribes, and Olympic National Park regulate intertidal harvest, although effective enforcement along the coast is limited. Trampling and souvenir collecting by visitors can have direct, localized impacts on rocky shore habitat and organisms, but the extent of this activity on the outer coast is not well documented (Skewgar & Pearson, 2011). The OCNMS condition report (2008) and management plan (2011) stated

[24] For more information on fisheries and management, please see the Commercial and Recreational Fisheries Chapter.

that while select habitat loss and degradation has occurred from human visitation activities, cumulative activities are unlikely to cause substantial or persistent harm to intertidal areas along the OCNMS shoreline.

Ocean noise

Many marine animals use sound to hear, communicate, find food, avoid predators, navigate, select mates, and more. Marine mammals in particular rely on sound for communication, navigation, and detecting food. Noise within the ocean can be natural: generated from animals, as well as waves, wind, storms, and other physical processes. Ocean noise can also be created by humans, through activities such as shipping and other vessel traffic, drilling, mining, and many other activities. Noise can even travel across ocean basins (Hatch & Broughton, 2015).

Coastal and ocean waters are getting noisier, and anthropogenic ocean noise (from humans) is a growing problem for marine ecosystems with increasing and more varied human activities taking place. Anthropogenic noise can either be acute (intense noise, generally for relatively short time periods) or chronic (lower intensity background noise). Acute noise can cause adverse physical and behavioral impacts, while chronic noise can limit marine animal communication range and ability to sense their environment (e.g. predator avoidance in eels and foraging time in bats). The frequency of noise (i.e., high pitch versus low pitch tones) has different effects on different animals, depending on their hearing sensitivity thresholds. NOAA and the U.S. Navy are actively researching noise in the ocean, with NOAA's focus on recording noise in marine sanctuaries to better understand the potential effects of human noise on our nation's marine protected areas (Hatch & Broughton, 2015).

The MSP Study Area has many acoustically active whale species, many of which are listed under the ESA and all of which are protected under the Marine Mammal Protection Act. Study Area waters are impacted by both chronic and accumulated acute anthropogenic noise sources, primarily from shipping as well as Navy training and testing activities. However, in the pelagic habitat, ocean noise pollution (cumulative acoustic signature of human activities) is currently not well characterized or evaluated for potential impacts on wildlife (Hatch & Broughton, 2015; Olympic Coast National Marine Sanctuary, 2011). Therefore, noise pollution remains a concern, yet more information is needed to assess the actual impacts to the Washington marine ecosystem, as well as any potential noise impacts a potential new use may have on wildlife.

Vessel strikes

Collisions between vessels and marine mammals, in particular large whales, is a known stressor throughout the world, particularly in areas where high ship traffic and whale populations intersect. Whales are vulnerable to strikes from all vessel types. Vessel strikes can lead to animal injury and death. Large vessel crews may not even notice when a strike has occurred, injured whales may not be noticed, and whale carcasses may not wash up on shore, so the number of whale strikes is greater than the documented incidents (National Marine Sanctuaries, 2015). In Washington, Blue whales, Fin whales, and Gray whales have been struck and killed by ships (Lance et al., 2011). OCNMS attempts to identify the degree of risk posed to whales and other marine mammals from ship strikes in the sanctuary by coordinating with the Northwest Marine Mammal Stranding Network to identify potential increases of incidents and supporting efforts to examine overlap areas of high marine mammal density and shipping lanes (Olympic Coast National Marine Sanctuary, 2011).

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2.2 Cultural and Historic Resources

Cultural and historic resources are an important part of the modern context and uses of the Washington coast and MSP Study Area. Washington's coastal area is rich with cultural resources including archaeological sites providing prehistoric records of native peoples' marine-oriented uses and traditional cultural properties for cultural practices, traditions, beliefs, lifeways, arts, crafts, or social institutions of a living community. Maritime history is embedded along Washington's coast, with many existing historic resources representing Euro-American maritime culture and shipwrecks.

American Indian archaeological resources

People have lived along Washington's shoreline and used the marine environment for thousands of years (United States v. Washington, No. C70-9213 (W.D.WA. 2015)). One of the earliest dated archeological sites on the Washington coast occurs within the boundaries of the Treaty of Neah Bay, establishing human presence for at least the last 6,000 years (Olympic Coast National Marine Sanctuary, 2011). It is likely that human presence along the west coast may have started as early as before 14,500 BP (ICF International, Southeastern Archeological Research, & Davis Geoarchaeological Research, 2013).

The native peoples of the Washington coast relied heavily on ocean and coastal resources and continue to do so today. Archeological sites, traditional oral histories, and ethnographies provide records for the types of marine-oriented uses the outer coast tribes participated in during prehistoric times and up to the signing of the treaties. These marine resources not only provided subsistence, but also played an integral role in culture, ceremonies, and economy. Native peoples harvested several species from the ocean, estuaries, and fresh waters including, but not limited to: salmon, steelhead, halibut, cod, sea bass, sole, and crabs. They also harvested shellfish, and were hunters of seal, sea lions, sea otters, and whales. These communities developed specialized gear for fishing, sealing, and whaling, including various types of seaworthy canoes optimized for hunting specific types of animals; dried kelp for fishing lines; and specialized hooks (United States v. Washington, No. C70-9213 (W.D.WA. 2015)).

Records of this activity can be found in various types of coastal archaeological sites and numerous anthropological reports. Sites include shell middens, villages, petroglyphs, burial grounds, fish weirs, canoe runs, traditional cultural properties, and others (ICF International et al., 2013). The modern shoreline and uplands adjacent to the MSP Study Area contain dozens of late prehistoric archeological sites. Some of these sites are known to occur within the intertidal zone, directly above the intertidal zone, and up to several kilometers inland. Specific examples of Native American sites listed in the National Register of Historic Places are: Ozette Indian Village Archaeological Site, Tatoosh Island, and Wedding Rock Petroglyphs (Olympic Coast National Marine Sanctuary, 2011). Enormous middens have also been discovered in La Push connecting native peoples to extensive use of the ocean (United States v. Washington, No. C70-9213 (W.D.WA. 2015)). There are likely undiscovered coastal archaeological sites in the area, Map 13 displays the output of a predictive model for upland archaeological sites developed by DAHP.

Due to changes in sea level since humans first arrived on the west coast, it is very possible that submerged prehistoric Native American archeological sites exist beneath the ocean. At about 19,000 BP, sea level was at its lowest, up to about 30 miles offshore from the present-day shoreline in some locations. Since then, sea level rose at various rates, pushing possible prehistoric occupants farther and farther inland (ICF International et al., 2013). BOEM modeled paleoshorelines from 19,000 BP to 1,000 BP in federal waters to illustrate how shoreline location changed over time (Map 13). Further analysis by BOEM indicates that much of the Study Area has a moderate likelihood of preserved submerged prehistoric sites, with a somewhat higher likelihood of preservation toward the south (ICF International et al., 2013).

Historic Resources

The Washington coast has a rich, maritime history. Europeans first laid eyes on the Washington coast possibly as early as 1579, yet mapping of this area began in the late 1700s. Sustained Euro-American settlement in Washington began in the 1850s, and the territory was declared a state in 1889. Maritime trade and commerce, processing, and resource extraction quickly became growing, profitable industries. Maritime trade and the foggy, dangerous conditions of the coast necessitated the establishment of lighthouses. Cape Disappointment light house at the mouth of the Columbia River, built in the 1850s, was one of the first lighthouses to be constructed along the Washington coast. Lifesaving stations operated by the U.S. Lifesaving Service (predecessor to the United States Coast Guard) were also established to assist mariners. Many lighthouses along the Washington coast remain intact and open to visitors (Washington State Department of Archaeology and Historic Preservation, 2011).

Communities sprouted and thrived along Washington's shoreline, using access to water for transporting natural resources such as fish, shellfish, and timber. Working waterfronts hosted canneries and seafood packers, lumber mills, pulp mills, and shipyards. As the region's sea-based commerce became increasingly profitable, recreational boating and tourism also thrived. The natural beauty of rugged shorelines drew people looking for waterfront vacations, and resulted in the construction of marine-oriented resorts, hotels, and campgrounds. These activities and industries shaped the history and culture of coastal communities, and many continue today, particularly shipping, fishing, aquaculture, seafood processing, timber, recreation, and tourism (Washington State Department of Archaeology and Historic Preservation, 2011).

Historical places along the coast provide a link to the past of the Washington coast. Historical resources include buildings, structures, sites, districts, and objects. Examples include light stations, historic districts, hotels, and architecturally distinct buildings. There are several historical resources listed on the National Register of Historic Places and the Washington Historic Register adjacent to the MSP Study Area (Map 14). Many more historical sites are listed in the Washington Historic Property Inventory (Washington State Department of Archaeology and Historic Preservation, 2015).

Shipwrecks

The Washington coast is home to perilous waters. Fog, waves, storms, strong currents, sand bars, and a rugged coastline made historical navigation a challenge. Over 180 ships were reported wrecked or lost at sea in or near Olympic Coast National Marine Sanctuary waters between 1808 and 1972. Ship types ranged from clippers and steam freighters to fishing boats and barges. Several wrecks are famous in local lore (as cited in (Olympic Coast National Marine Sanctuary, 2011). The Columbia River bar at the southern end of the MSP Study Area is reported to be the second most dangerous bar crossing in the world (Oregon Solutions, Cogan Owens Cogan, & Oregon State University Institute of Natural Resources, 2011), and thus many shipwrecks have occurred there. Discovered archaeological shipwreck sites represent just a small portion of known losses at sea (Map 14), and many more sites may remain undiscovered within the MSP Study Area.

Potential impacts to archaeological and historic resources

Historical places, archaeological sites, and traditional cultural properties include areas important for maintaining cultural identities, places with spiritual power, healing, or associated with origins or important events, and areas with aesthetic significance for people today. These sites could be disturbed by new uses that impact the seafloor, and also may be subject to various levels of visual disturbance from new ocean uses.

Some historical resources and traditional cultural properties may also be subject to various levels of visual disturbance sensitivity from new ocean uses, such as offshore wind. Washington analyzed how far offshore different height objects would be visible from shore (Map 15). This coarse assessment is useful to understand what may be visible from the coast, yet specific assessments for individual projects will be needed to evaluate the full potential visual impact from each new use proposal.

Understanding and integrating cultural landscapes into marine use decisions is important. In an effort to meaningfully integrate the nation's cultural heritage into marine management decisions, the Department of Commerce and the Department of the Interior, through the Marine Protected Areas Federal Advisory Committee (MPA FAC), developed a Cultural Landscapes Approach (CLA). The CLA provides a means for developing new levels of information about marine areas and their resources by including integration of knowledge, memories, and empirical observations of tribal indigenous cultural groups and other resource users. The CLA aims to make cultural resources and human relationships with the environment visible across time and culture (Marine Protected Areas Federal Advisory Committee, 2011). This approach may be useful for Washington State when making decisions for new ocean and coastal uses.

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2.3 Socioeconomic Setting

Washington's coastal communities adjacent to the MSP Study Area are generally rural, with natural resources playing an important part in the economy and cultural character of these communities. Parks, forests, and natural areas cover much of the land area of the four coastal counties: Clallam, Jefferson, Grays Harbor, and Pacific (Maps 1 and 16). The Pacific coastal areas of Clallam and Jefferson counties are quite remote and sparsely populated, while Grays Harbor and Pacific Counties have several small incorporated and unincorporated communities along the coast (Map 16). Key industries include natural resource-based industries (fishing, aquaculture, and timber), tourism, manufacturing, and government services. The five federally recognized tribes: Makah, Quileute, Hoh, Quinault Indian Nation, and Shoalwater Bay (Map 2), are also an integral part of the socioeconomic character of the coast. All except Shoalwater Bay have treaties with the United States that extend their fishing rights as much as 40 nautical miles west into the Pacific. Coastal communities are exposed to several natural hazards and unique coastal challenges such as powerful winter storms, tsunami events, and resulting inundation. Continued participation in marine-resource based industries, a healthy marine ecosystem, and a future with a sustainable local economy are among commonly shared visions of many coastal residents (Butler et al., 2013; Kliem, 2013).

Funding through the Marine Spatial Planning process was provided to gather social and economic information for coastal counties and tribes adjacent to the MSP Study Area. This socioeconomic chapter briefly summarizes the extensive information provided through these projects[1]. Readers are encouraged to consult these reports and other references for further details on the socioeconomic context of Washington's coastal communities.

- *Economic analysis to support marine spatial planning in Washington*. The purpose of this project was to develop the tools and data to characterize existing economic conditions on the Washington coast. This report provides economic information for each of the coastal counties and tribes adjacent to the MSP Study Area. Available at: http://www.msp.wa.gov/wp-content/uploads/2014/02/WMSP_2015_small.pdf.
- *Social indicators for the Washington coast integrated ecosystem assessment.* This report documents the development and assessment of social indicators of human wellbeing for the four coastal counties. The social indicators assessment is part of the Washington integrated ecosystem assessment that enables understanding of the social, economic and ecological components of ocean health. Available at: http://www.msp.wa.gov/wp-content/uploads/2015/03/SeaGrant_SocialIndicatorsReport.pdf.
- *Washington's working coast: An analysis of the Washington Pacific coast marine resource-based economy.* This project provided baseline economic information and assembled qualitative marine resource-based economic information through a narrative of interviews with a representative group of coastal stakeholders. Available at: http://media.wix.com/ugd/e2eea5_7a4796fc90c3f86ff0ae22e675bd6b55.pdf.

County profiles

Primary socioeconomic measures for the four coastal counties are presented in Table 2.3-1. The four coastal counties are rural along the Pacific coast, and in Clallam and Jefferson Counties the majority of

[1] Economic information specific to each marine industry is provided under the relevant chapters within Part 2 of this MSP.

their population centers are in areas not adjacent to the Pacific Coast[2]. The median household income for each county is below the state average, and the unemployment rates are higher than the state average for each county.

The ocean economy represents a significant portion of the total economy for the four coastal counties. Pacific County has the highest percentage with over a quarter of total jobs (26%) within ocean industries (i.e., living resources, marine transportation, tourism and recreation, ship and boat building, offshore mineral extraction, and marine construction), and Grays Harbor County has the lowest proportion at 13%, yet it still represents a significant element of total employment (Table 2.3-2). Ocean economy gross domestic product (GDP) represents approximately 10% of the total GDP for Clallam, Jefferson, and Grays Harbor Counties, and about 18% of the total GDP for Pacific County (National Oceanic and Atmospheric Administration, 2016).

Table 2.3-1. Socioeconomic parameters for the four coastal counties[3] and Washington state.

	Clallam County	Jefferson County	Grays Harbor County	Pacific County	Washington State
Population[4]	72,500	30,700	73,300	21,100	7,061,530[7]
Median household income[5]	$46,033	$46,320	$42,405	$39,830	$59,478
Gross regional product[6]	$2,033 million	$ 703 million	$2,038 million	$519 million	$408,049 million
Industry diversity index[5,6] (0 = more diverse, values closer to zero indicate higher diversity)	0.7340 (increase over time)	0.6609 (increase over time)	0.5848 (increase over time)	0.4647 (slight increase over time)	0.5220 (increase over time)
Unemployment[5]	9.2%	9%	11.8%	10.6%	7%
% of individuals below the poverty level[7]	14.6%	13.3%	19.0%	17.2%	13.4%

[2] Clallam County's major cities are on the Strait of Juan de Fuca; Jefferson County's major cities are on Puget Sound.

[3] These numbers are county-wide, and are not limited to just the Pacific Ocean coastal portion of the counties.

[4] Estimated for 2014. Source Taylor et al., 2015.

[5] As of 2013. Source Poe et al., 2015.

[6] This value is from the Ogive index, an index for economic diversity. A value of 0 on the Ogive index would mean that employment is equally distributed among the sectors, and would be the most diverse. Therefore, an increase in the Ogive index means that employment is unequal and that there is a larger concentration in fewer sectors.

[7] 2009-2013 five year estimate. Source: United States Census Bureau, 2013.

Table 2.2-2. Ocean economy[8] of individual counties, the Pacific Coastal counties combined, and Washington State.

Ocean-related industries	Countywide - 2013[9]				Statewide – 2013[9]	
	Clallam County	Jefferson County	Grays Harbor County	Pacific County	4 Pacific Coastal County Total (2011)	Washington State (2011)
Employment	3,098	1,262	2,702	1,651	8,713	121,131
Self employment	179	201	327	278	985	6,936
% of total jobs	14%	16%	13%	27%	8% of WA ocean jobs	4% of total WA jobs
Total wages	$78.7 million	$26.2 million	$72.3 million	$39.5 million	$216.7 million	$4.9 billion
Gross Domestic Product (GDP)	$185.1 million	$63.4 million	$171.6 million	$98.9 million	$519 million	$11.8 billion
% of total economy GDP	9.1%	9.1%	8.4%	19%	4.4% of WA ocean economy	2.9% of total WA economy

Clallam County

Clallam County extends along the northernmost portion of the Olympic Peninsula and makes up the northwestern most corner of the state. It covers 1,739 square miles (1.11 million acres). Much of Clallam County is under public ownership. Federal lands, primarily Olympic National Park (325,047 acres) and Olympic National Forest (197,782 acres) make up 47% of the county's acreage. State Forest Lands account for another 92,525 acres (Taylor, Baker, Waters, Wegge, & Wellman, 2015). The County is bordered by the Pacific Ocean to the west and the Strait of Juan de Fuca to the north. The shoreline

[8] Ocean related industries included in the NOAA ENOW data are: living resources, marine transportation, tourism and recreation, ship and boat building, offshore mineral extraction, and marine construction. For more information on methods and specific industry codes please see: https://coast.noaa.gov/digitalcoast/tools/enow.

[9] Online ENOW explorer data from 2013. (National Oceanic and Atmospheric Administration, 2016)

adjacent to the MSP Study Area (Pacific Ocean) is almost entirely within Olympic National Park (Map 1) or Indian reservation land (Makah and Quileute reservations) (Map 2).

The industries in Clallam County with the highest employment are government (32.7%); wholesale and retail trade (17%); health care and social assistance (10.7%); and accommodation and food services (10.1%) (Taylor et al., 2015). Government is a significant source of employment in Clallam County, with a location quotient of 1.7 times more concentration in government sector as compared to the rest of the state (Butler et al., 2013). Economic development strategies focus on manufacturing, marine services, natural resources, renewable energy, tourism, and others. The Port of Port Angeles is a major port in Clallam County, and significantly contributes to the county's economy with marine terminals, marinas, airports, and log yards; the Port is not located within MSP Study Area (Taylor et al., 2015).

A zip code based analysis revealed that the Pacific Coast-based businesses accounted for only 4% of Clallam County's ocean-dependent activity, while the Strait of Juan de Fuca ocean-dependent activity accounts for the remaining 96% (NOAA Coastal Services Center, 2014).

Jefferson County

Jefferson County is located on the Olympic Peninsula south of Clallam County. The county is about 1,800 square miles (1.15 million acres) with most of the land in public ownership. Federal lands, primarily Olympic National Park (538, 849 acres) and Olympic National Forest (166,299 acres) make up about 61% of the county's total area, while State Forest Lands account for 14,703 acres (Taylor et al., 2015). The County is bordered by the Pacific Ocean on the west and Puget Sound, Hood Canal, and the Kitsap Peninsula on the east. The shoreline adjacent to the MSP Study Area (Pacific Ocean) is almost entirely Olympic National Park or Indian reservation land, including the Hoh reservation and the northwest corner of the Quinault Indian Nation reservation (Maps 1 and 2).

The industries with the highest employment include government (27.1%); wholesale and retail trade (14%); accommodation and food services (12.8%); and health care and social assistance (10.7%) (Taylor et al., 2015). Economic development strategies are focused on industries such as manufacturing, arts and culture, education, healthcare, marine trades, and others. The Jefferson County Economic Development Council is working to increase access to investment capital in the county (Taylor et al., 2015).

A zip code based analysis revealed that the Pacific Coast-adjacent businesses accounted for 14% of Jefferson County's ocean-dependent activity, while the Puget Sound ocean-dependent activity accounts for the remaining 86% (NOAA Coastal Services Center, 2014).

Grays Harbor County

Grays Harbor County is the largest of the four coastal counties covering an area of about 1,900 square miles (1.22 million acres). Grays Harbor County is bordered by the Pacific Ocean on the west, and has topography of mountains, foothills, and river valleys. Grays Harbor estuary covers 58,000 acres and extends inland about 25 miles. Federal lands make up about 12% of the county, including Olympic National Forest (138,724 acres) and a small part of Olympic National Park (6,662 acres). The Washington Department of Natural Resources (DNR) manages about 31,300 acres of State Forest Lands within the county. The majority of the Quinault Indian Nation reservation is within Grays Harbor County, however the community of Queets is located in Jefferson County and has hundreds of residents (Map 2) (Taylor et al., 2015).

More than 60% of the county's population lives in incorporated areas. The county has nine municipalities, five of which are adjacent to the MSP Study Area: Aberdeen, Cosmopolis, Hoquiam, Ocean Shores, and Westport (Taylor et al., 2015). The industries with the highest employment include government (27.4%); wholesale and retail trade (14%); manufacturing (12.7%); and health care and social assistance (10.8%) (Taylor et al., 2015).

The Columbia Pacific Resource Conservation and Economic Development District, which Grays Harbor County is a part of, identified four natural resource-related industrial clusters considered integral to the Columbia-Pacific region economy: forest products; fishing, fish processing, and related aquaculture; agriculture; and food products. Grays Harbor County has highlighted recent success in the tourism industry cluster, with increased hotel/motel tax revenues and taxable retail sales. The Port of Grays Harbor is located within Grays Harbor County and plays a major role in the coastal economy (Taylor et al., 2015).[10]

Pacific County

Pacific County is about 933 square miles (596,902 acres) in size. It is bordered on the west by the Pacific Ocean, and the Columbia River to the south. Pacific County includes the Long Beach Peninsula, which separates Willapa Bay from the Pacific Ocean. Less than 1% of the county is under federal ownership, yet DNR-managed State Forest Lands account for 23,340 acres, about 4% of the county. More than 70% of the county, close to 420,000 is forested (Taylor et al., 2015). The Shoalwater Bay Tribe is located along the northern shoreline of Willapa Bay (Map 2).

A vast proportion (98.8%) of the county is unincorporated. The county has four municipalities: Ilwaco, Long Beach, South Bend, and Raymond. The industries with the highest employment include government (29.9%); manufacturing (12.3%); accommodation and food services (11.9%); and wholesale and retail trade (10%) (Taylor et al., 2015). The agriculture, forestry, fishing, and hunting industry also makes up a significant portion of employment in Pacific County (9.2%), with a location quotient of more than 2.7 times more concentration in this sector as compared to the rest of the state, and more than 9.4 times more concentration is this sector as compared to the rest of the country (Butler et al., 2013). In fact, the Brookings Institute ranked Pacific County as the fourth most fishing-intensive local economy in the U.S. by share of total 2012 earnings (Kearney et al., 2014).

Pacific County's vision for their economic future includes maintaining and enhancing a rural lifestyle by promoting long-term development of viable agricultural, aquaculture, forest, and fisheries resources; promoting economic development that is compatible with the area's resources; and promoting the safety and general welfare of all residents (Taylor et al., 2015). Four Port Authorities are located in Pacific County: the Port of Willapa Harbor, Port of Peninsula, Port of Ilwaco, and Port of Chinook.[11]

Tribal socioeconomic profiles

There is considerable economic interaction among the tribes, tribal members, and the non-Indian communities on Washington's coast. Economic activity is often intertwined, as tribal members work and shop off-reservation, non-Indians are employed by the tribes, and many tourists and local residents visit tribally-owned businesses, which include resorts and marinas. In addition, commercial and subsistence fishing activities occur off-reservation in Usual and Accustomed Fishing Grounds (U&A) for treaty

[10] For more information on the Port of Grays Harbor, see 2.7: Marine Transportation, Navigation, and Infrastructure.

[11] For more information on the ports of Pacific County, see 2.7: Marine Transportation, Navigation, and Infrastructure.

tribes[12], both on the ocean and in freshwater bodies (rivers and lakes). Yet each tribe has its own socioeconomic identity. Available socioeconomic information for each of the five federally recognized tribes adjacent to the MSP Study Area is summarized below.

Makah Tribe

The Makah Reservation is located on the northwestern most tip of the Olympic Peninsula and covers about 44 square miles (30,142 acres), including Tatoosh and Waadah Islands and the Ozette Reservation (Map 2). Physically isolated from Washington and even other parts of Clallam County, the primary community on the Makah Reservation, Neah Bay, is 60 miles from Forks and 75 miles from Port Angeles. Harsh natural conditions accompany the rural setting of this area. The area receives over 100 inches of rain per year and is subject to high winds. Over 40% of the reservation is on slopes exceeding 30% grade and only 6% of the roads are paved (Taylor et al., 2015).

In 2010, 1,414 individuals were living on the reservation, and in 2005 tribal enrollment was at 2,534. During a period from 2009-2013, the main industries of employment were public administration (30.7%); agriculture, forestry, fishing and hunting, and mining (18.6%); and educational services, and health care and social assistance (17.7%). The U.S. Census Bureau estimates that almost 55% of these jobs were government positions, including tribal employees, and other local, state, and federal employees. Median earnings for workers on the Makah reservation during this time were $27,102 (Taylor et al., 2015).

The economy of the reservation is very dependent on two sectors: tourism and fishing. Neah Bay is said to offer some of the best saltwater fishing in the United States, and the marina serves as a base for one of Washington's most important locations for charter halibut fishing. Other popular tourist activities include hiking, surfing, kayaking, and diving. Tourism-related tribal enterprises include the Warmhouse Restaurant, Cape Resort, Hobuck Beach Resort, and Makah Mini-Mart. Another attraction is the Makah Museum. Tourism slows down during the winter months, resulting in layoffs during the winter. The tribe is interested in attracting wintertime tourists to increase year-round revenue and jobs in this industry (Taylor et al., 2015). Commercial fishing is also a large part of the Makah's economy. About 70 commercial fishing vessels operate out of Neah Bay. There is also a Cape Flattery Fisherman's Co-op with a small processing plant, and the Makah Tribe owns the commercial fishing dock in Neah Bay (Taylor et al., 2015). More information on the economics of commercial fishing on the Makah Reservation is described in Section 2.4.

Other economic industries on the reservation include the forestry industry and the commercial filming industry which utilizes the area and tribal services. Plans for the Makah Tribe's economic future is to expand the four tourist-oriented enterprises in the short term, and possibly develop a 9-hole golf course and/or a high end resort or retreat center in the long term. Challenges include developing opportunities for younger tribal members with college degrees who wish to stay on the reservation (Taylor et al., 2015).

Quileute Tribe

The Quileute Reservation covers approximately 2,161 acres, including the community center of La Push, a fishing community, and James Island, a sea stack just off the coast connected at extreme low tides. The reservation is located on the Olympic Peninsula and is roughly bounded by the Quillayute River, the Pacific Ocean, and the Olympic National Park (Map 2). Much of the reservation is surrounded

[12] The four coastal treaty tribes adjacent to the study area are: Hoh Tribe, Makah Tribe, Quileute Tribe and Quinault Indian Nation. See Section 1.6 for detailed description of treaty rights.

by wilderness areas managed by the National Park Service. La Push is about 15 miles west of Forks (Taylor et al., 2015).

In 2010, 460 individuals were living on the reservation, and 2015 estimated tribal enrollment is 777 members. Industries with the highest level of employment from 2009-2013 were educational services, and healthcare and social assistance (46.1%); public administration (28.9%); and agriculture, forestry, fishing and hunting, and mining (13.8%) industry clusters. The median earnings for workers on the Quileute Reservation were $24,205 from 2009-2013. According to the Quileute Tribe's Comprehensive Economic Development Strategies document completed in fall of 2013, the primary sources of employment are government services (tribal and federal), commercial ocean fisheries, subsistence river fisheries, and the Quileute Ocean Park Resort. Annual surveys show that many households derive some proportion of their income from fishing. The fishing and tourism industry are both seasonal (Taylor et al., 2015).

Tourism is a source of employment and income to the tribe. The remoteness and natural beauty of the area attracts many visitors. The reservation offers a wide range of recreational activities including wildlife viewing, nature photography, coastal hiking, boating, fishing, kayaking, surfing, camping, swimming, and storm watching. The Quileute also host a number of tribal events, many of which are open to the public. Tourism-related businesses include the Quileute Oceanside Resort complex (open year-round), and River's Edge Restaurant. The Quileute Tribe also owns and operates the marina at La Push. The tribe is also engaged in commercial fishing and hatchery operations (Taylor et al., 2015).

Plans for the economic future of the Quileute Tribe include the creation of jobs as a major priority. Plans include improvements to the Oceanside Resort, development of a permanent cultural center/museum facility, development of the tribal owned Ki'tla Business Parks in Forks, expansion of commercial fishing, and acquiring broadband internet service. Similar to the Makah Tribe, a challenge for the Quileute is to develop new employment opportunities for the next generation (Taylor et al., 2015).

Hoh Tribe

The Hoh Reservation is located on the Olympic Peninsula in Jefferson County, about 25 miles south of Forks and 80 miles north of Aberdeen. The reservation is bounded to the north by the Hoh River and includes one mile of ocean shoreline to the west. Until recently, the reservation was about one square mile (640 acres). But the changing course of the Hoh River and resulting flooding of tribal homes and facilities prompted land purchases and land transfers starting in 2008. Today, the reservation encompasses more than 900 acres (Map 2) (Taylor et al., 2015).

In 2010, there were 116 individuals living on the reservation. There are about 230 enrolled tribal members. The isolated location of the reservation limits employment opportunities primarily to commercial fishing (21.2%) or to jobs directly with the tribe (75.8%). The U.S. Census Bureau estimates that almost 82% of jobs in 2009-2013 were government positions, including tribal employees as well as other local, state, or federal positions. The median earnings during 2009-2013 for workers on the Hoh Reservation were estimated to be $38,462 (Taylor et al., 2015).

The Hoh depend on the fish and wildlife of the Hoh River and their other usual and accustomed areas for both subsistence and their commercial economy. The Hoh manage tribal forestlands to provide a safe and healthy environment for tribal members and protect basic watershed functions for the cultural and economic needs of the tribe. The Hoh tribe plans for minimal and infrequent harvests of tribal forest lands, and to focus the regeneration of trees on species for cultural use. Plans for the future include using the additional lands to the reservation for housing and government facilities and opportunities for economic development (Taylor et al., 2015).

Quinault Indian Nation

The Quinault Reservation is located in the southwestern corner of the Olympic Peninsula. The reservation covers 208,150 acres, is mostly forested and is crossed by several major rivers including the Queets, Raft, and Quinault Rivers (Map 2). The Pacific Ocean lies to the west, Queets village to the north, Lake Quinault is on the east side, and Moclips is to the south. The rainforest climate brings 80 inches of precipitation on the coastal end and up to 150 inches at higher elevations. A total of 173,000 acres of the reservation is tribal and Bureau of Indian Affairs-managed forestland (Taylor et al., 2015).

In 2010, 1,406 individuals were living on the reservation. As of 2015, total tribal enrollment was 2,928. Communities within the Quinault Reservation include Amanda Park, Queets, Qui-nai-elt Village, Santiago, and Taholah. During a period from 2009-2013, industries providing the highest proportion of employment include educational services, and health care and social assistance (33.2%); public administration (28%); and arts, entertainment, and recreation, and accommodation and food services clusters (11%). Additional industries include agriculture, forestry, fishing and hunting, and mining (5.2%); construction (5.2%); and manufacturing (4.5%). According to the U.S. Census Bureau, almost 70% of jobs were government employees. The median earnings for workers on the Quinault Reservation during 2009-2013 were $24,375 (Taylor et al., 2015).

Three primary industry clusters are central to the Quinault Indian Nation: Hospitality and Tourism, Fisheries, and Forestry. Tourism-related businesses include the Quinault Beach Resort and Casino (located off-reservation in Ocean Shores), the Quinault Sweet Grass Hotel (also in Ocean Shores), Quinault Marina and RV Park (located in Ocean Shores, yet currently closed), guided fishing trips, and the Quinault Tribal Museum. Fisheries-related businesses include the Quinault Pride Seafood Processing Plant in Taholah, the Quinault National Fish Hatchery, and a fishing support facility at Westport Marina (Taylor et al., 2015).

Plans for the future include upgrades to the fish processing plant in Queets, proposed development of land-based sand and gravel resources, development of biomass for renewable energy, and relocating the Taholah village beyond the tsunami hazard zone (Taylor et al., 2015).

Shoalwater Bay Tribe

The Shoalwater Bay Reservation is located in Pacific County on the north shore of Willapa Bay. The reservation is slightly more than one square mile with 440 acres of uplands and 700 acres of salt marsh and tide flats (Map 2). The upland portion of the reservation is mostly a steep ridge, leaving only a narrow piece of developable land along the shoreline, and much of this strip is within the tsunami hazard zone. Unlike the other four coast tribes, the Shoalwater Bay Tribe did not sign a treaty with the federal government, and therefore does not have secured U&A or hunting areas (Taylor et al., 2015).

In 2010, 82 individuals were living on the reservation. The tribe has more than 300 enrolled members. From 2009-2013, the industries with the highest proportion of employment were arts, entertainment, and recreation, and accommodation and food services (33.3%); educational services, and health care and social assistance (26.4%); and public administration (18.1%). The U.S. Census Bureau estimates that over 40% are government employees, and about 43% are jobs with private companies. The median earnings for workers on the Shoalwater Bay Reservation during 2009-2013 were $23,958 (Taylor et al., 2015).

Current Shoalwater Bay tribal-owned businesses include the Shoalwater Bay Casino, San Verbena Seafood & Grill, Tradewinds on the Bay (condos for rent), and Georgetown Station convenience store and gas station. The tribe has recently added several hundred acres and plans to add additional housing outside of the tsunami hazard zone (Taylor et al., 2015).

Economic impact modeling of ocean and coastal uses

The Marine Spatial Planning process funded an economics report that estimated economic contributions of commercial and recreational fisheries, aquaculture, and recreation and tourism to local and state economies. Cascade Economics produced estimates of economic contributions using an input-output model that captures the key, measurable linkages between economic activities. Estimates of jobs and labor income were created and are referred to as total effects and are the sum of "direct", "indirect", and "induced" effects. Direct effects are those that arise directly from the spending being studied. For example, spending comes from recreational trip-related expenditures. Indirect effects are those that relate to the businesses that receive a portion of the direct expenditures in exchange for goods and services provided to the focal economic activity. Induced effects are then those related to the spending of personal income earned by the owners and employees of these linked businesses. The "economic multiplier" effect captures the degree to which indirect and induced activities expand the impact of direct expenditures on the economy of interest (see Figure 2.3-1).[13] Specific economic contribution numbers (total labor income and total jobs) estimated for each industry are discussed within the respective chapters in the MSP. These numbers highlight the economic importance of these ocean and coastal industries to the coastal region and the State. The Cascade Economics report provides additional explanation of the IMPLAN input-output model and its supporting data.

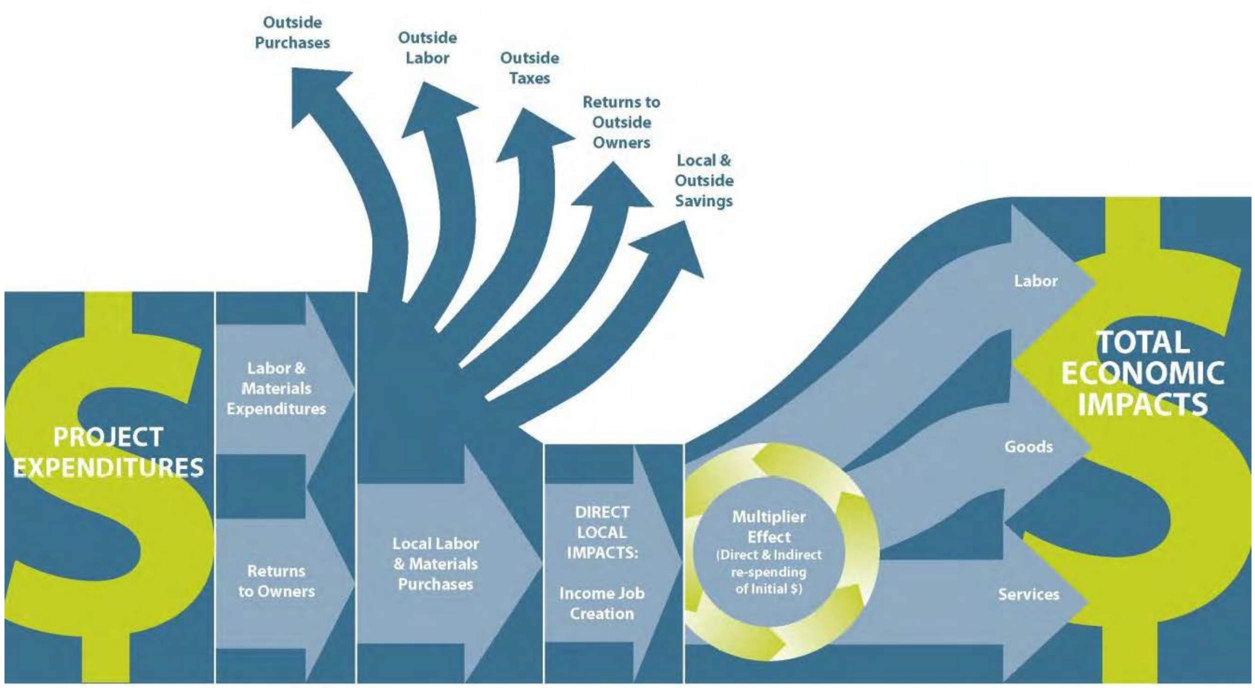

Figure 2.3-1: Illustration of regional economic impacts, leakage, and multiplier effects. Source: (cited in Taylor et al., 2015)

[13] 2014 commercial landings data and recreational trip data were used to calculate economic contributions of those sectors, while 2013 data was used for this purpose for the aquaculture sector. In all cases the multipliers used were derived using IMPLAN models based on 2012 regional economic data.

Coastal hazards and community vulnerability

Washington coastal communities are exposed to a number of natural hazards which may influence human safety, businesses, and quality of life. Community vulnerability to hazards can be defined as the attributes of a human-environmental system that increase the potential for hazard-related losses or reduced performance. Characteristics that influence vulnerability include exposure, sensitivity, and resilience of a community. Socioeconomic factors, such as population and economy within hazards zones, vary by community (Wood, 2007). While a detailed analysis of coastal community vulnerability is out of scope for the MSP, a general description of WA community exposure to coastal hazards is provided to give context to the challenges these communities face today and into the future.

Coastal natural hazards posing a risk to communities adjacent to the MSP Study Area include severe storms, flooding, coastal erosion, landslides, earthquakes, and tsunamis. With regards to the severe storm hazard, all four coastal counties are vulnerable to high winds (Washington Emergency Management Division, 2013), and exposure to severe storms increased from 2005 to 2010 (Poe, Watkinson, Trosin, & Decker, 2015). Coastal storms can impact other natural hazards, such as erosion and flooding events. Coastal storm surge flooding affects low elevation areas along the Pacific Ocean coast and is most common during winter storm events, generally from November through February. Coastal flooding results from the combination of storm-driven surges and daily tides, with maximum flooding occurring when the peaks of storm-driven surges coincide with high tides. Flooding may destroy structures through wave force, erosion scour, or impact from debris. All of the MSP Study Area coastal counties are susceptible to wind and barometric tidal flooding (Washington Emergency Management Division, 2013).

Coastal erosion is another hazard within the MSP Study Area and has been studied from Point Grenville south to the Columbia River. Erosion in this area is generally cyclical, with shoreline erosion occurring during the winter storm months and accretion during the calmer summer months. Areas of localized chronic and episodic erosion have impacted communities such as Westport, North Cove (a.k.a. Washaway Beach), Ocean Shores, and Cape Disappointment and is often influenced by jetties and coastal sediment supply. Coastal storms can increase erosion (Talebi, 2015).

Landslides occur when gravity overcomes the strength of the soil and rock in a slope. Saturation, erosion, ground shaking, and human action are contributing factors to landslides. According to the Washington State Emergency Management Division (EMD), areas adjacent to the MSP Study Area that are at risk of landslides include portions of Jefferson County, areas of Grays Harbor County near Aberdeen, and some areas of Willapa Bay in Pacific County (Washington Emergency Management Division, 2013).

As discussed in the Geomorphology section, a subduction earthquake is a large looming hazard for the Washington coast. Washington communities are also vulnerable to other earthquakes generated from other faults. Earthquakes can damage infrastructure, disrupt public services and utilities, impact businesses, and risk injury and loss of life. All four MSP coastal counties are considered to be among the most vulnerable in Washington to earthquakes (Washington Emergency Management Division, 2013).

Earthquakes may also cause tsunamis. Tsunamis can be generated by distant earthquakes, such as those occurring in Alaska or Japan. Yet Washington’s tsunami hazard zone planning is modeled after a potential 9.1 magnitude Cascadia Subduction Zone (CSZ) earthquake located along the West Coast, from northern Vancouver Island down to northern California. This earthquake could produce the largest tsunamis along the coast. Many communities adjacent to the MSP Study Area have significant proportions of their populations within the tsunami hazard zone. Examples of coast wide, county, tribal, and select city populations within the hazard zone are given in Table 2.3-3. These numbers do not account for the thousands of visitors to coastal areas every day (Washington Emergency Management Division, 2013).

Table 2.3-3. The total number and community proportions of residents residing within the tsunami hazard zone for select coastal communities. Source: Washington Emergency Management Division, 2013

County, Tribe, or City	Proportion of Community Population	Number of Residents[14]
Four coastal counties combined	24%	42,972
Clallam County	3%	2,239
Jefferson County	7%	1,692
Grays Harbor County	42%	28,447
Pacific County	50%	10,595
Makah Tribe	59%	802
Quileute Tribe	15%	54
Hoh Tribe	61%	62
Quinault Indian Nation	42%	572
Shoalwater Bay Tribe	85%	59
Aberdeen (Grays Harbor County)[15]	72%	11,781
Long Beach (Pacific County)	100%	1,281

Many coastal communities are planning and preparing for subduction zone generated tsunamis, including: posting evacuation route and hazard zone signs; establishing 24-hour warning capabilities; and promoting public readiness through community education (Washington Emergency Management Division, 2013). Some of the tribes are planning to use recently acquired lands to build housing and

[14] Based on 2000 U.S. Census data

[15] The city of Aberdeen has the greatest number of residents within the tsunami hazard zone, representing the greatest number of people at risk in one local community.

other public facilities outside of the tsunami hazard zone[16,17] (Taylor et al., 2015). Project Safe Haven, a community and tribal effort to identify vertical evacuation options initiated by EMD and the University of Washington, developed several community strategies for tsunami evacuation preparedness (Washington Emergency Management Division, 2013). One example is the Ocosta Elementary School, which is the first vertical evacuation structure built in North America. It is located in Grays Harbor County, just south of Westport. A vertical evacuation platform was built on top of the gym roof and is designed to hold 1,000 people, which provides safe refuge for the children and local community (Buehner, 2016).

In addition to tsunami preparation, Washington's coastal communities, in coordination with EMD, the Federal Emergency Management Agency (FEMA), Ecology's Coastal Program, Washington Sea Grant, and other local, state, and federal agencies are working to understand, prepare for, respond to, and mitigate against various natural hazards to reduce risk and increase community resilience. One example is the Coastal Hazards Resilience Network that brings together federal and state government agencies, academic institutions, consultants, and nonprofit organizations to improve regional coordination, integration, and understanding of coastal hazards[18].

Coastal stakeholder views

People living on Washington's coast hold important, diverse views on social and economic issues and interests that are a part of defining the character of these coastal communities. Summary reports of workshops and interviews completed for the MSP process have helped to capture the various community perspectives of Marine Resource Committee (MRC) participants and other coastal stakeholders in the four coastal counties.

Two MSP reports, which capture coastal stakeholder interests and perspectives in further detail are:

- *Washington's working coast: An analysis of the Washington Pacific coast marine resource-based economy* (2013) by Butler et al. provides a qualitative analysis of interviews conducted with the Marine Resources Committees and other coastal stakeholders. Available at: http://wa-working-coast.wix.com/wa-workingcoast

- *Coastal voices: A report on citizen priorities, interests, and expectations for Marine Spatial Planning along Washington's Pacific coast* (2013) by Kliem summarizes Marine Resources Committee workshops held to identify interests, priorities, and expectations for MSP. Available at: http://www.msp.wa.gov/wp-content/uploads/2013/06/060413_Coastal-Voices-Version-Final.pdf

Perspectives of coastal residents and stakeholders provide important context on social and economic interests and concerns for the planning process to consider. The section below briefly

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[16] The Quileute Reservation occupies a small piece of land on the coast that is threatened by tsunamis. The Quileute will use 275 acres of newly acquired land from the Olympic National Park as a new site for the Tribal Council's headquarters, tribal school, pre-school, senior center, and other facilities to provide tsunami protection for the tribe (Taylor, Baker, Waters, Wegge, & Wellman, 2015). Other acreage was acquired in the same legislation (PL 112-97), but is not going to be developed (e.g., wetlands).

[17] The Quinault Indian Nation village of Taholah is in the official tsunami hazard zone. Over 1,000 residents, as well as the Taholah Mercantile, jail, courthouse, daycare facility, Head Start facility, and a K-12 school are located within the tsunami zone. The Quinault are currently developing a master plan to relocate Taholah to higher ground beyond the tsunami and flood hazard zone (Taylor et al., 2015).

[18] www.wacoastalnetwork.com

highlights some of the frequent themes and perspectives conveyed by coastal stakeholders and residents to provide an insight into commonly expressed views regarding social and economic interests and concerns. Of course, not all residents and coastal users share these perspectives, and even within these interviews and workshops there were a diversity of views.

A primary common theme expressed among these comments and workshops include the importance of protecting and valuing the natural-resourced based economy of coastal communities. The marine resource-based economy was described as part of their coastal heritage, and the desire to protect existing marine resource industries, such as fishing and aquaculture, was shared across participating stakeholders (Butler et al., 2013; Kliem, 2013).

Other themes included the importance of a healthy marine ecosystem and access to natural resources for jobs and to enjoy the rural, natural character of the coast. Protecting these attributes for the benefit of future generations is important to many stakeholders. Many participants shared concerns that new ocean uses would negatively impact local communities and economies, through displacement of local long-term jobs and impacts to the ecosystem. Stakeholders expressed the need to use science as well as local, traditional knowledge in the decision-making process to avoid and minimize impacts. Another theme was meaningful local community involvement in decision-making for siting new uses to reduce conflicts, and balancing the perspectives and needs of local, state, and national interests. Many stakeholders highlighted the unique, multi-jurisdictional management of marine resources in Washington (e.g. fisheries co-management with tribes, and the presence of the Olympic Coast National Marine Sanctuary) and desire for a unique approach and management solution for new uses within the MSP Study Area (Butler et al., 2013; Kliem, 2013).

Future trends

While each coastal county and community has a distinct socioeconomic profile, many share similar challenges and opportunities into the future. One example of a socioeconomic challenge common to all four coastal counties is the relatively low proportion of working age residents (Poe et al., 2015). Coastal residents have observed that many working age individuals have moved to areas that offer more job opportunities, and there is a concern that without a strong workforce, the coastal region will become less competitive, attract fewer businesses, and lose innovative thinkers (Butler et al., 2013). In contrast, many of the tribes have relatively high proportions of young residents entering the workforce, and are pursuing ways to provide job opportunities for those who wish to stay and work on the reservations (Taylor et al., 2015).

Coastal communities have also identified many opportunities for socioeconomic growth for an economically sustainable future. For example, many governments and economic council plans reflect the intention of increasing economic diversification, while continuing to strengthen their existing industries. Resources for small, local business start-ups and expansion are in place and more are under development. Throughout many coastal communities, sustainable natural resource-based industries are seen as vital to a healthy, local economy, and will likely continue to be a focus into the future (Butler et al., 2013; Taylor et al., 2015).

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2.4 Commercial, Recreational, and Tribal Fisheries

Fishing is a longstanding and important use of the MSP Study Area. In acknowledgement of this importance, the law requires this Plan to"[r]ecognize that commercial, tribal, and recreational fisheries, and shellfish aquaculture are an integral part of our state's culture and contribute substantial economic benefits"(RCW 43.372.005(3)(i)). This chapter promotes that recognition by summarizing how fisheries use the MSP Study Area and by describing their importance to fishing communities and the state economy.

The information presented in this chapter primarily follows that of two reports produced for the coastal marine spatial planning process: a fishing sector report (Industrial Economics Inc., 2014) and economic analysis (Taylor, Baker, Waters, Wegge, & Wellman, 2015). Readers are encouraged to consult these reports for further information. Additionally, the basic fisheries statistics on which the two reports rely are collected and maintained by WDFW and the coastal treaty tribes. Most of these core statistics are publically available upon request, subject to certain restrictions in place to protect confidentiality. Information presented in this chapter is a combination of information provided by WDFW, Industrial Economics (2014), Taylor et al. (2015), and other sources as cited in the chapter.

As an opening note on terminology, the term "commercial" in this chapter should not be read to cover tribal fisheries. Many tribal fisheries do resemble commercial fisheries in terms of where and how they fish, the markets into which the fish are sold, and in their contributions to the coastal economy. However, tribal fisheries are described separately because they are conducted under special authorities held by the tribal governments. Likewise, tribal members also harvest fish and shellfish non-commercially, for ceremonial and subsistence purposes, yet they would not refer to their fishing activities as "recreational." The specific fishing activities of the four coastal treaty tribes are described below.

Summary of History and Current Use

Fishing Community Engagement and Dependence

The MSP Study Area contains some of the most productive regions of the California Current ecosystem and supports abundant fish and shellfish resources. Washington's coastal tribes have depended on these resources for thousands of years as did Euro-American settlers since first arriving in the state in the mid-1800s. Today, many coastal communities remain highly engaged, reliant, and dependent on commercial, recreational, and tribal fisheries. Communities highly engaged in fishing may have, for example, relatively high pounds of landings or number of fishing permits, while communities highly reliant on fishing may have relatively high values of landings per capita or fishing permits per capita. Communities with high levels of both engagement and reliance on fishing are considered to be highly dependent on fishing (Jepson & Colburn, 2013).

Recent studies have evaluated the engagement, reliance, and dependence of Washington's communities on fishing. A NOAA study identified a number of communities located adjacent to the MSP Study Area as being some of the most highly fishing dependent communities[1] on the West Coast (Table 2.4-1) (Norman, in progress 2017). This classification is based on both fisheries variables and social variables. Although La Push is not included in the table based on the most recent NOAA study, it was identified as a community with high fishing dependence and engagement in a 2007 NOAA study

[1] Fishing dependence was a combination of reliance and engagement indices for commercial and recreational fisheries. For details on methods, please see Norman, in progress, 2017.

(Norman et al., 2007). The methodology in the 2017 study relies on social data available via the census that is only available for a census designated place. As an unincorporated community, this data is not available for La Push and therefore it was not included in the 2017 study. However, La Push is recognized as one of several important fishing communities in the MSP Study Area, serving not only tribal fishers, but also non-tribal commercial and recreational fishers. Detailed information about the methodology and data used is available in the full NOAA reports. In addition, a national study by the Brookings Institute found that Pacific County was the fourth most fishing intensive local economy in the United States in terms of the share that fishing contributed to total county earnings (Kearney et al., 2014).

The fisheries related activities of the coastal communities adjacent to the Study Area are the focus of this chapter and are described in more detail below. However, the Plan also recognizes that the Study Area's fishery resources support a broader set of communities. Although there are relatively few places for fishing vessels to safely access the ocean in Washington, those few places provide access to a relatively broad geographic area. The Strait of Juan de Fuca, Columbia River, and Grays Harbor provide the major access points while La Push and Willapa Bay provide marinas and boat launches for smaller vessels. Furthermore, the Strait opens the Study Area to the many ports of the Puget Sound region and the Columbia River gives reliable access to the ports not just in Washington, but in Oregon as well. As a result, Bellingham and Astoria-Warrenton have been as engaged in the fisheries of the Study Area as communities like Westport and Ilwaco that are located alongside it.

Conversely, the Plan also recognizes that non-tribal fishing communities adjacent to the Study Area are engaged in and dependent on fishing grounds elsewhere, such as in Puget Sound and off Oregon, California, and especially Alaska.[2] Revenue earned by commercial fishing and seafood businesses from fisheries, like the Bristol Bay Sockeye Salmon fishery, contribute to the viability of these businesses and to activity in Washington's state and coastal economies. The Albacore Tuna fishery offers another example as much of the commercial and recreational catch occurs beyond the 700 fathom Study Area, yet still supports the communities of the coastal counties.

Table 2.4-1: WA coastal communities adjacent to the MSP Study Area with high commercial fishing dependence Source: Norman in progress 2017

Bay Center, Pacific County
Chinook, Pacific County
Ilwaco, Pacific County
Neah Bay, Makah Indian Reservation, Clallam County
Taholah, Quinault Indian Reservation, Grays Harbor County
Tokeland, Pacific County
Westport, Grays Harbor County

[2] The Treaty Tribes are restricted to their Usual and Accustomed ocean fishing grounds.

Fisheries Management

The fisheries occurring within the MSP Study Area are diverse and managed by a complex mix of state, federal, regional, and international processes. Most every species supporting fisheries in the MSP Study Area migrates across or straddles jurisdictional boundaries meaning that cooperation and coordination between governments and fisheries management processes is the norm instead of the exception. In addition, as further discussed in the Treaty Rights chapter, Washington is unique in the nation for having tribal governments that hold treaty rights to fish in ocean waters. Several other tribes hold treaty rights to fish in Puget Sound or the Columbia River for species that are impacted by fisheries in the MSP Study Area. Cooperation and co-management with tribal governments occurs throughout a number of state, regional, and international fisheries management processes. Cooperation with state, tribal, federal, and international governments also occurs at the level of science and monitoring. This section briefly outlines the existing fisheries management forums. More details are given below in the descriptions of individual fisheries.

In Washington, the principal authority for managing fisheries is delegated to the Department of Fish and Wildlife (WDFW). The Department includes the Washington Fish and Wildlife Commission, which consists of nine citizen members appointed by the Governor. The Commission holds rule-making authority and is responsible for setting fish and wildlife policy for the Department. It was established to provide an open and deliberative process that promotes public involvement and confidence in management decisions. The Department's mandate to preserve, protect, and perpetuate fishery resources includes both state and offshore waters, with the latter term defined as the "marine waters of the Pacific Ocean outside the territorial boundaries of the state, including the marine waters of other states and countries."

The Pacific Fishery Management Council (PFMC) is a similarly open and deliberative process established by Congress to manage federal fisheries off the coast of Washington, Oregon, and California. The PFMC's voting membership consists of six governmental representatives and eight private citizens. The governmental representatives include representatives from WDFW and the state fisheries management agencies of Oregon, California, and Idaho; NOAA Fisheries; and a tribe with federally recognized fishing rights. The citizen members are nominated by the Governors of each state and are appointed by the U.S. Secretary of Commerce. PFMC makes conservation and management recommendations that are reviewed for consistency with national standards and other applicable federal laws and implemented into federal regulation by NOAA Fisheries. PFMC organizes its work primarily around four fishery management plans (FMPs)—Salmon, Groundfish, Coastal Pelagic Species, and Highly Migratory Species—and a Fishery Ecosystem Plan.

The Pacific States Marine Fisheries Commission (PSMFC) was created as an interstate compact agency in 1947 with Washington, Oregon, and California as the original members and Idaho joined in 1963 and Alaska in 1968. The PSFMC coordinates research activities, monitors fishing activities, and collects data and maintains databases on salmon, steelhead, and other marine fish. The PSMFC does not regulate fisheries, but provides recommendations and a forum for coordination between states for state-managed fisheries.

In the international arena, five major processes directly affect fisheries in the MSP Study Area. Three operate under treaties between the U.S. and Canada: the International Pacific Halibut Commission for Pacific Halibut, the Pacific Salmon Commission, and the Pacific Hake/Whiting Treaty. These bilateral management agreements work to monitor the shared stocks and to establish sustainable catch level and allocate them among the two nations. The halibut and salmon stocks covered by the agreements involve the fisheries and interests of Alaska as well. The other two processes affect fishing for Albacore Tuna.

Albacore management involves both the Inter-American Tropical Tuna Commission and the Western and Central Pacific Fisheries Commission and brings in the interests of many nations with fishing interests in the Pacific Ocean.

Fishery Sectors

The general convention is to classify fisheries, or fishery sectors, based on some combination of the main species or species group harvested, the area fished, and the fishing gear used. However, other factors may be used to differentiate one type of fishing from another and the definition of a fishery sector may differ depending on the management purpose being addressed. Furthermore, broader species groups, e.g. "Groundfish", are sometimes used to summarize the activities of multiple fishery sectors. As the fisheries and fisheries sectors are described and grouped differently within the Cascade economic report (2015) compared to the chapter, Table 2.4-2 translates the groupings. Each fishery sector is discussed individually below. Within each sector description, the main fisheries occurring within the Study Area are also discussed in detail. However, while discussed separately, the Plan recognizes that there are links between sectors with businesses relying on revenue from more than one fishery sector. Note that some fisheries may have both a commercial and recreational component, while others only have one or the other. Furthermore, due to data availability, maps are only available for those fisheries listed in the far right column. Map 55 shows the combined commercial and recreational fishing intensity for the MSP Study Area.

Table 2.4-2: Fisheries Sector Groupings and Available Maps

Sector	Fishery Grouping	Fisheries Described in Chapter	Economic Report Description	Fisheries Use Maps Available
Commercial	Highly Migratory Species	- Albacore Tuna	- Albacore Tuna[3]	- Albacore Tuna
	Coastal Pelagic Species	- Pacific Sardine	- Coastal Pelagic Species	- Pacific Sardine
	Groundfish	- Fixed Gear - Bottom Trawl - Midwater Rockfish Trawl - Whiting (Shoreside and At-Sea)	- At-Sea Pacific Whiting - Shorebased Fisheries o Whiting Trawl o Non-Whiting Trawl o Non-Trawl	- Groundfish (Bottom Trawl) - Pacific Whiting - Sablefish (Fixed Gear)
	Shellfish	- Dungeness Crab - Pink Shrimp - Spot Prawn - Razor Clam	- Dungeness Crab - Shrimp - Other Species[4]	- Dungeness Crab - Pink Shrimp - Razor Clam
	Salmon	- Ocean Troll - Gillnet	- Salmon Troll - Salmon Net	- Salmon Troll
	Pacific Halibut	- Pacific Halibut	- Other Species[3]	

[3] Some tables report within a general Highly Migratory Species grouping, which is referenced as being comprised of mostly Albacore Tuna.

[4] Other species includes spot prawn, Pacific halibut, and hagfish.

	Other	- Hagfish	- Other Species[3]	
Recreational	Highly Migratory Species	- Albacore Tuna	- Albacore Tuna	- Albacore Tuna
	Groundfish	- Bottomfish	- Bottomfish	- Bottomfish and Lingcod
	Shellfish	- Razor Clam - Dungeness Crab	- Razor Clam	- Razor Clam
	Salmon	- Salmon	- Salmon - Steelhead	- Salmon
	Halibut	- Pacific Halibut	- Pacific Halibut	- Pacific Halibut

The fisheries use maps referenced in Table 2.4-2 and throughout this Chapter were developed by the WDFW to summarize the available information on areas of high importance to fisheries as required by RCW 43.372.040(6)(c). The primary purpose of the maps is to identify the footprint of each fishery (where fishery has occurred or has the potential to occur); and secondarily, to characterize the areas of high, medium, and low intensity within them. The intensity rankings refer to the relative level of activity within each fishery. They are not rankings of one fishery against another (i.e. a "high" in one fishery may have seen less overall activity than a "low" or "medium" from another, larger fishery).

WDFW used three general approaches to create the maps based on fishery dependent (i.e. logbook or observer) data, professional judgment of fishery managers and participants, or a combination of the two depending on the information available for each fishery:

1. Maps based on fishery-dependent data and percentile rankings: Each hexagon was evaluated for units of fishing effort (i.e. number of set or tows per hexagon) and all hexagons within the fishery's footprint were ranked as:
    a. "High"- Top 25% of hexagons
    b. "Medium"- Middle 50% of hexagons
    c. "Low"- Bottom 25% of hexagons
2. Maps based on logbook data with criteria-based intensity definitions- Due to limited location and effort data presented in logbooks, each hexagon was evaluated based on available effort data and other criteria that correlates with high activity in the particular fishery (e.g. depth, distance from shore)
3. Maps based on interviews with fishery participants and managers- Some fisheries have no logbook or observer data that can be used to evaluate effort level. Therefore, WDFW consulted with fishery participants and managers to determine intensity levels and footprints of select fisheries.

Major sources of uncertainty should be kept in mind when interpreting these maps. First, the intensity rankings do not represent an estimate of the impact or conflict that would be expected if a new use were to occupy the same space. Conflict in an area ranked as "low" intensity could still cause a significant adverse economic impact to a fishery and fishing communities. Evaluation of the conflict and impact that could arise between a fishery or fisheries and a proposed project would require careful study and examination of all available information. Second, uncertainty as to the footprint of a fishery and the areas of fishing intensity arises from both data limitations and annual variability in the fisheries. Regulations, environmental factors, movement of target species, and other factors affect fishing effort, distribution of the fleet, and community engagement in each fishery year to year. Footprints and intensity levels should be expected to vary.

More specific details for the methods behind producing each map can be found in [*Cite WDFW report on Fisheries use analysis and methods report (when finalized)*].

Commercial Fisheries

This section describes the various commercial fisheries operating within the MSP Study Area. The focus is on their general size in terms of pounds landed and ex-vessel revenue earned; basics of how they are regulated; and key aspects of their operations such as gears used, number of participants, major species targeted, and the areas and time of year in which they fish.

The core information on commercial fishing activity comes from fish receiving tickets, commonly referred to as "fish tickets," that record of the transaction between a vessel owner or operator making a delivery of commercially caught fish and the purchaser. The fish ticket reports the species or species group landed, amount of each species (typically in weight but sometimes in numbers of fish), and the price paid by the buyer for each species or species group landed (i.e. as noted above, "ex-vessel" revenues). Fish tickets are sent to WDFW and maintained in a state database that is also shared with state and federal fisheries management agencies through the Pacific States Marine Fisheries Commission (PSMFC) PacFIN database together with the data from Oregon and California.

The commercial fishing activities by the four counties at focus are shown in Table 2.4-3. Grays Harbor and Pacific Counties have been the most active on all metrics of participation (Table 2.4-3). Coastal county residents make up the largest proportion of commercial fishing vessel owners (299 vessels) and ex-vessel revenue ($40.4 million) from landings into coastal ports (Table 2.4-4). Commercial fishermen residing outside of the Washington coastal county region also fish in the MSP Study Area and use coastal ports. As Table 2.4-4 shows, there were over 230 vessels registered to Washington residents residing outside of the outer coast region, accounting for more than $23.5 million in ex-vessel revenues in coastal ports in 2014. There were also 72 vessels registered in Oregon and 90 vessels registered elsewhere that delivered landings to Washington coastal ports in 2014 (Taylor et al., 2015). Table 2.4-5 summarizes the total landings, ex-vessel revenue, and price of each species management group landed within the Washington coastal counties.

Table 2.4-3: Landings, ex-vessel revenues, and participation by county for Washington coast commercial fisheries in 2014.[1] Source: WDFW as reported in Taylor et al. (2015).

County[5]	Round weight (1,000 lbs)	Ex-vessel revenue ($1,000)	Number of dealers	Number of vessels
Clallam	2,020	2,975	20	88
Grays Harbor	97,355	59,742	45	354
Pacific	29,206	29,285	30	364
Wahkiakum	779	966	7	80
WA Coast totals	129,360	92,967	98	700

Table 2.4-2: Count of vessels and total non-tribal ex-vessel revenues in 2014 in Washington coastal ports by vessel owner's address. Source: WDFW as reported in Taylor et al. (2015).

Vessel owner's region	Number of vessels	Ex-vessel revenue ($1,000)
Washington coast[6]	299	40,439
Other Washington	232	23,657

[5] There have been no non-tribal commercial fisheries landings recorded in Jefferson County ports along the outer Washington coast since 2007.

[6] Vessel owner's address is in one of the five Washington coast counties

Oregon	72	13,143
Elsewhere	90	13,326
Unknown	7	1,058
No vessel ID	-	1,344
Total	700	92,967

Table 2.4-3. Landings, ex-vessel revenue, and average revenue per pound in Washington coastal ports by fisheries management group, non-tribal fishery sector, 2014 and 2004-2014 range. Source: WDFW as reported in Taylor et al. (2015).

Management Group	Landings in 2014 (1,000s of round weight lbs)	Landings range during 2004-14 (1,000 lbs)		Ex-vessel revenue in 2014 ($1,000)	Ex-vessel revenue range 2004-14 ($1,000 2014 inflation adjusted)		Revenue per lbs in 2014	Revenue per lbs (11 year average) (2014 inflation adjusted)
		Low	High		Low	High		
Groundfish	51,182	26,702	80,517	9,324	5,819	13,703	0.18	0.16
Salmon	2,568	799	2,568	5,152	2,022	5,152	2.01	2.18
Crab	8,615	5,615	19,540	36,567	12,503	43,511	4.24	2.58
Shrimp	30,543	3,382	30,543	16,398	1,868	16,398	0.54	0.49
Coastal Pelagic	17,666	9,759	78,936	3,208	521	8,212	0.18	0.10
Albacore	17,184	10,084	18,600	20,216	11,333	28,216	1.18	1.21
Razor Clam [7]	282	103	282	560	182	589	1.98	1.86
Other[8]	1,444	268	2,833	1,769	512	2,832	1.23	1.01

[7] The numbers from the shellfish category reported in Taylor et al. (2015) included geoduck harvest from the Strait of Juan de Fuca. WDFW updated these figures to include just razor clams commercially harvested in the Study Area.

[8] Commercial fisheries included in the "other" category of this table are: Pacific Halibut, Spot Prawn, and Pacific hagfish.

Total	129,360	-	-	92,967	-	-	-	-

Groundfish

The fishery sectors described here are grouped together in large part because they are managed under the PFMC's Groundfish FMP. Groundfish is an umbrella term used to describe a diverse group of species that prefer seafloor habitats. The PFMC Groundfish FMP includes over 90 species— two-thirds of which are species of rockfish—although the great majority of commercial landings and revenues come from just a handful of stocks. These key commercial stocks include Pacific Whiting, Sablefish, Dover Sole, Petrale Sole, Lingcod, and Shortspine Thornyheads.

In the aggregate, the groundfish fisheries provide some of the largest annual landings into coastal ports (Table 2.4-5). From 2004-2014, groundfish was the largest fishery by volume in all years except 2012 and 2013. This high volume of landings is attributable mainly to the Pacific Whiting fishery. However, the low price per pound paid for Pacific Whiting limits the overall ex-vessel revenue earned by the groundfish sector.

While often described together, there are multiple, distinct fishery sectors managed under the Groundfish FMP and operating in the Study Area that show diversity in terms of their fishing methods, fishing grounds, and target species. A first level of distinction can be made between vessels that use fixed gear (i.e. hook-and-line or pot gear) and those that use trawl gear. Among vessels using trawl gear, there is a further distinction between vessels that target Pacific Whiting ("whiting") and those that fish for species other than Whiting ("non-whiting" or "traditional groundfish"). Another distinction applies within non-whiting trawl between vessels using bottom trawl gear and vessels using midwater gear to target rockfish in the water column. Within whiting, there is a distinction between the at-sea sector, where catch is processed aboard vessels, and a shoreside sector, where vessels land their catch in port. Each groundfish sector is described below.

Fixed Gear

Sablefish is the main target of the fixed gear sector. The species made up roughly 86% of total landings by weight and 95% of the total ex-vessel revenue over 2004-2014 in the fixed gear sector. Total fixed gear landings ranged from 0.9 million lbs to 1.7 million lbs and earning $2.1 million to $5.8 million in revenues. Sablefish is highly valued as seafood with a strong export market. The ex-vessel price per pound received for fixed gear caught Sablefish is one of the highest on the coast and has been greater than that paid for Dungeness Crab in some years. In 2014, at least 37 vessels recorded at least $1,000 of landings value in this sector, with 29 vessels receiving $10,000 or more.

Fixed gear vessels target sablefish across the U.S. West Coast, yet the MSP Study Area, especially north of Point Chehalis, has provided some of this sector's most important fishing grounds. Submarine canyons and the continental shelf break and upper slope provide key fishing grounds for this sector (Map 17). Off Washington, fixed gear vessels have been required to fish seaward of 100 fathoms since 2002 because of the need to reduce catch of Yelloweye Rockfish. The fish are targeted using baited hooks or pots that linked on longlines and placed and left on or near the seafloor and later retrieved. A string of hooks or pots are commonly referred to as a "set."

Bottom trawl and midwater rockfish trawl

As noted, non-whiting trawl vessels use bottom trawl or midwater trawl gear to target a variety of species. Bottom trawl gear has been the more common gear during the 2004-2014 period and is the basis of the use map. Bottom trawl vessels target flatfish (e.g. Petrale and Dover Sole), Sablefish, and many other species and are active over much of the Study Area's continental shelf and slope habitats (Map 18). The midwater targeting strategy focuses on rockfish, primarily Yellowtail Rockfish, and occurs on the shelf where schooling rockfish can be found. This fishery was depressed during 2004-2014 compared to historical levels because of measures taken to rebuild Canary and Widow Rockfish and so no maps were produced for this fishing strategy. Midwater trawling has rebounded some since 2011 and is expected to increase further because the allowable harvests of Canary and Widow are greatly increased now that both species have been declared rebuilt.

Overall, non-whiting trawl accounted for between approximately 1.1% and 3.8% of total Washington coast landings during 2004-14. Ex-vessel revenue value ranged from $0.6 million to $1.4 million during that same time period. Sablefish earns the highest ex-vessel value per lb among trawl fishery species although Petrale Sole is a highly valued species as well. The management changes made by PFMC over the 2000s to rebuild overfished rockfish and reduce fishing capacity substantially reduced Washington's bottom trawl fleet. However, the MSP Study Area still provides important fishing grounds for the Astoria-based (Oregon) bottom trawl fleet, which is the most active bottom trawl port on the West Coast. Pacific County, Whatcom County (Puget Sound), and Grays Harbor County are where the majority of non-whiting groundfish landings in Washington occur.

Whiting

As noted above, the fishery for Pacific Whiting is conducted by both shorebased and at-sea catcher vessels. The two are reported separately, highlighting the difference in the way the catch contributes to the local economy. All whiting catcher vessels use midwater trawl gear designed to fish in the water column, although trawling can take place close to the seafloor. Vessels in the at-sea sector tend to be larger and have more horsepower with the ability to stay at sea for long periods of time.

Whiting are caught predominately off of Washington and Oregon, with the amount of Whiting caught off of Washington varying from year to year, particularly in the at-sea sectors (Table 2.4-6). Shoreside vessels, in contrast, tend to stay as close to port as possible because the flesh quality of Pacific Whiting is improved if processed quickly. The continental shelf and upper continental slope areas of the Study Area are key fishing grounds (Map 19). Avoidance of salmon and rockfish bycatch has been a key influence on where the fishery has occurred during the 2004-2014 time period with the bycatch constraints pushing the fishery into smaller areas than would otherwise be fished if whiting catch were the only consideration.

The shorebased Pacific Whiting trawl fishery is conducted off the coasts of Washington and Oregon with active ports at Westport and Ilwaco in Washington. Landings have consistently been the largest component of total commercial landings on the Washington coast in terms of weight from 2004-2014, with the exception of 2012 and 2013 when it was surpassed by Pacific Sardine landings. In 2014, ex-vessel revenue was $5.5 million. Half of the 10 vessels participating in 2014 received at least $250,000 in ex-vessel revenue.

Within the at-sea sector, there are two distinct sectors: motherships and catcher-processors. In the mothership sector, catcher vessels deliver to a mothership vessel, which only processes whiting. In the catcher-processor sector, vessels both catch and process their own catch. Each of the at-sea sectors operates under a co-op system that operates to divide the PFMC's quotas for whiting and bycatch species like Darkblotched Rockfish. The catcher-processors, mothership processing vessels, and many of the mothership catcher vessels are based in Puget Sound.

Table 2.4-4: Total coastwide annual and estimated catch off the Washington coast by vessels operating in the non-tribal, at-sea Pacific whiting sector. Source: WDFW as reported in (Taylor et al., 2015)

Sector	Sector total 2014 (metric tons)	Sector total range during 2005-14 (metric tons)		Washington share in 2014	Washington share range 2005-14	
		Low	High		Low	High
Catcher-Processors	103,486	34,620	108,121	0%	0%	52%
Motherships	62,109	24,091	62,109	14%	13%	91%

Salmon

Salmon are perhaps Washington's most historic and iconic fish. They are highly valued as seafood and earn the second highest revenue per pound of the species fished in the MSP Study Area (11-year average of $2.18 per lb.). The total value of the fishery, however, is limited by the low allowable catches relative to fisheries like Dungeness Crab and Pacific Whiting (see Table 2.4-5). The commercial salmon fisheries have been greatly reduced from historic levels primarily because of population declines across several salmon runs and the major changes in how salmon stock were shared with the treaty tribes that followed from the Boldt Decision in 1974 (see Tribal Fisheries Section below and Section 1.6 for details on treaty rights).

Two distinct sectors commercially fish for salmon in the MSP Study Area: the ocean troll fishery and the gillnet fishery. The PFMC is the main process for setting seasons in the troll fishery, while WDFW sets seasons for the gillnet fisheries. Both fishery sectors, however, are intertwined with the larger, complex salmon management processes that involve the three West Coast states as well as Alaska and Idaho, Canada, and the several tribes holding rights to fish for salmon across the Pacific Northwest. The core challenge across all salmon fisheries has been to focus harvest on hatchery raised fish and healthy wild populations while reducing pressures on the wild stocks of high conservation need.

Ocean Troll

Troll gear is a type of hook and line gear that vessels pull through the water using bait or artificial lures to attract fish. Vessels operate over a wide range of ocean waters with the most fishing activity occurring in depths between 20 and 80 fathoms north of the Queets River and between 20 and 60 fathoms south of that landmark (Map 20). Chinook and coho salmon are the main targets of the troll fleet. Chinook is the more frequently landed fish in this sector, constituting about 84% of landings by weight and earning 94% of ex-vessel revenue in 2014. Total ex-vessel revenue was about $2.4 million in 2014. In general, ocean troll salmon fetches a relatively high price, with $4.30 per lb. in 2014 and an 11-year average of $4.08 per lb. The number of licenses WDFW issued to ocean troll vessels ranged from 152 to 157 between 2004 and 2014. In 2014, at least 111 vessels recorded at least $1,000 of salmon troll landings, 79 of which received at least $10,000 in ex-vessel revenue from those landings. On average, Pacific County has reported the greatest share of ex-vessel revenues (49.4%), although Grays Harbor County surpassed Pacific County in 2013.

Gillnet

The gillnet fisheries operate in Willapa Bay, Grays Harbor, and the Columbia River.[9,10] WDFW regulates the two estuaries separately with seasons timed to intercept the adult fish returning to their natal streams to spawn. Vessels deploy and actively tend free floating nets that entangle the fish in their mesh. Nets can be no longer than 1,500 feet long and there are mesh size regulations depending on harvest area. In addition to Chinook and Coho, gillnetters also target Chum Salmon. In 2014, Coho constituted about 57% of landings by weight and about 50% of landings by value, although these numbers can vary greatly from year to year. Between 2004 and 2014, the number of gillnet licenses has ranged from 192-195 in Willapa Bay and 63 to 64 for Grays Harbor. Landings have ranged from a low of 0.5 million lbs in 2007 to a high of 2 million lbs in 2011 with corresponding ex-vessel revenues of $1 million to $3 million. The 11-year annual average ex-vessel price for salmon gillnet fishery landings for 2004-2014 was about $1.51 per lb. In 2014, 138 vessels recorded at least $1,000 of salmon net landings on the Washington coast, with 72 vessels receiving at least $10,000 in ex-vessel revenue from those landings.

Highly Migratory Species

Albacore Tuna

The Albacore Tuna commercial fishery is managed under the PFMC's Highly Migratory Species FMP. Because of the stock's wide ranging migration, stock assessments, and international agreements, regulation of the fishery is minimal and it is one of the few fisheries on the West Coast where participation is still open to entry from new fishers. Albacore are caught in Washington by both large troll vessels that harvest far offshore, and by locally based smaller troll vessels. Canadian vessels also fish in U.S. waters and make landings in Washington under a treaty between the U.S. and Canada. The fishery happens in the summer and late fall when the fish migrate to the West Coast. While most of the fishing occurs outside the MSP Study Area, within the Study Area fishing is most common between 30 and 50 nautical miles offshore but sometimes closer in to 20 nautical miles (Map 21). The Albacore Tuna fishery has the highest participation level among the Washington coast fishery sectors, with between 221 and 338 unique vessels making landings into Washington ports each year. Many vessels that participate in the salmon troll fishery also fish for albacore.

Washington coast Albacore landings ranged from about 10 million lbs to 18.6 million lbs from 2004-2014. Ex-vessel values ranged from about $11.3 to $28.2 million during that same time period. The average ex-vessel price in 2014 was about $1.18 per lb, with an 11-year average of $1.21 per lb (Table 2.4-5). In 2014, 210 vessels received at least $10,000 in ex-vessel revenue from tuna landings on the Washington coast. Westport (Grays Harbor) and Pacific County land the vast majority of Albacore on the Washington coast.

Coastal Pelagic Species

The PFMC's coastal pelagic species (CPS) FMP consists of Northern Anchovy, Market Squid, Pacific Sardine, and Pacific Mackerel. These species are caught mostly by vessels using purse seine gear. Off Washington, Pacific Sardine and Northern Anchovy are the main commercial species caught with Pacific Mackerel landed incidentally. WDFW authorized a trial Pacific Mackerel fishery for the first time in 2016. Small scale harvest of anchovies occurs in the nearshore, including state waters, Willapa Bay, and Grays Harbor. Anchovies are generally used for bait, and the majority of anchovies are landed in Grays Harbor.

[9] The Columbia River fishery is not included in this discussion as it is outside the MSP Study Area.
[10] Spatial data are unavailable to produce a map of the salmon gillnet fisheries in the estuaries for this MSP.

The CPS fishery has brought in relatively high volumes of landings (up to 78.9 million lbs in 2012), yet low value per lb ($0.10 per lb as the 11-year average from 2004-2014). However, this fishery is also highly volatile (the volatility being driven by Pacific Sardine) with landings as low as 9.7 million lbs during 2004-14, with large swings from year to year. Ex-vessel revenue from CPS landings in Washington ranged from about $0.5 million to $8.2 million from 2004-2014, with $3.2 million landed in 2014 (Table 2.4-5). In 2014, 10 vessels recorded at least $1,000 of revenue from CPS landings in Washington, seven of which received at least $10,000 from CPS landings.

Pacific Sardine

Sardine harvest is prohibited in state waters, with the federal water fishery open from April 1 to December 31. Sardines are landed mostly in Grays Harbor County, which has accounted for about 75% of the ex-vessel revenue values on average for sardines. Washington's share of coast-wide sardine harvest has increased recently, due to the changing focus in California to squid, and the proximity of the fish to Westport (Map 22). In 2015 and 2016, the Pacific Sardine fishery was closed by the PFMC because the stock biomass had dropped below a threshold biomass limit. The stock is known to fluctuate in abundance and may rebound above the limit if environmental conditions become favorable.

Shellfish

Dungeness Crab

Dungeness Crab have been the biggest revenue earner among the commercial species. Ex-vessel revenue ranged from $12.5 million to $43.5 million during 2004-2014 (Table 2.4-5), and earned the most coastal fisheries revenue for 9 of those 11 years. They are highly valued as seafood both locally and internationally and earn the highest average price per lb on the coast. The 11-year average ex-vessel price was $2.58 per lb. The price has been on an increasing trend since 2010, as markets for live crab in Asia have continued to develop. Prices reached extraordinary levels in 2014 with buyers paying $4.24 per lb on average over the year and over $6.00 per lb in March, April, and May. Dungeness Crab can fluctuate strongly in abundance from year to year because of variability in ocean conditions that affect survival and settlement of the larvae; the annual harvest fluctuates in kind. For example, crab landings were 5.6 million lbs in 2004 and 19.5 million lbs the following year.

Fishery participants trap the crabs using baited pots. Pots are deployed on soft bottom in depths ranging from 30 to 600 feet (5 to 100 fathoms) and are fished on lines, a single line to each pot, with length depending on the water depth. Crab are harvested along the entire Washington coast, including inside Grays Harbor, Willapa Bay, and the Columbia River yet the most intensive fishing takes place in the southern half of the MSP Study Area (Map 23). The primary landing ports and processing facilities are in Westport, Chinook, Tokeland, South Bend and Ilwaco. Neah Bay and La Push on the northern coast are minor ports for crab, and product landed there is typically sent elsewhere for processing. Growth in this aspect of the industry drives increasing prices and economic benefits for the industry and coastal communities.

WDFW manages the Dungeness Crab fishery in coordination with the coastal treaty tribes and the fisheries management agencies of Oregon and California. Coastwide coordination occurs on a number of issues including a tri-state agreement that establishes procedures for opening the season. WDFW and the coastal treaty tribes negotiate annual management agreements to determine how harvest within the tribal U&As will be shared. Special Management Areas (SMAs), which close portions of the tribal U&As to non-tribal vessels for part or all of the fishing season, and delayed season opening dates have been the main tools for sharing the catch. Tribal participation in the crab fishery began to increase after the 1994 Rafeedie Decision established that the Stevens Treaties applied to shellfish as well.[11] The tribal fishery gradually increased after 1994 until reaching current levels in terms of harvest in the mid-2000s. Since 2004, on average, the tribal fishery has accounted for just over 20% of the Dungeness Crab landings on the coast. This same figure was 1% on average over 1990-1994.

In terms of participation, 192 vessels recorded at least $1,000 of Dungeness Crab landings on the Washington coast in 2014, representing the second highest participation level among the Washington coast fishery sectors. Of those, 117 vessels received at least $100,000 in ex-vessel revenue. Although historically Dungeness Crab fishermen participated almost exclusively in the crab fishery, currently many participate in multiple fisheries in order to sustain their businesses year round. The fishery is highly competitive and causes a race for crab where the bulk of the harvest is within the first two months of the season.

The season begins December 1 and closes September 15 of the following year, except where state-tribal agreements have dictated otherwise or when crab quality delays are put in place. In recent years, agreements have kept areas north of Grays Harbor closed to the commercial fishery until January. The delayed season openings have led to concerns about higher competition and use south of Westport. Furthermore, WDFW may close the fishery for other reasons, such as closure for insufficient meat quality or domoic acid to ensure a safe product in the market place.

Pink Shrimp

Pink (a.k.a. “Ocean”) Shrimp are caught using trawl gear that is designed to fish slightly off the seafloor. Most shrimp trawl vessels are “double-rigged” meaning that they tow two nets, one on either side of the vessel. The fishery operates in depths of 300 to 750 feet (50 to 125 fathoms) off the Washington and Oregon coasts during season that runs from April 1 to October 31 annually (Map 24). Westport and Ilwaco are the two key landing ports with Westport receiving the bulk of the landings. In seafood markets, Pink Shrimp are often referred to as cocktail shrimp.

WDFW manages and coordinates regulations of the Pink Shrimp fishery with the Oregon Department of Fish and Wildlife, as Oregon based fishing vessels fish in the MSP Study Area as well. Volumes of shrimp landings have increased since 2012 with 30.5 million lbs landed on the Washington coast in 2014 (over double of what was landed in 2013). Ex-vessel revenues have similarly been increasing, with $1.9 million earned in 2007 to $16.4 million in 2014. This may be partially due to the value of shrimp also rising, with a price of $0.54 per lb in 2014, which is higher than the 11-year average of $0.49 per lb (Table 5). In 2014, 32 vessels recorded at least $1,000 of pink shrimp landings on the Washington coast, including 26 vessels that received at least $100,000 in ex-vessel revenue from those landings. Shrimp abundance, improved processing capacity, and other factors have contributed to the expansion of this fishery in Washington over recent years. More plans to increase shrimp processing capacity in Westport and the recent purchase of the idle shrimp processing plant in South Bend may further boost this industry.

Spot Prawn

The commercial spot prawn fishery is relatively new, starting in 1999. The fishery occurs along the outer coast of Washington between March 15 and September 15, about 20 to 40 nm offshore at depths between 420 and 600 feet (70 and 100 fathoms). Gear used in this fishery is primarily pot longline. The fishery has been managed as a limited-entry fishery, with eight licenses currently in circulation; between three and five of these licenses are actually active. Participants in this fishery typically also participate in

[11] More information on the Rafeedie Decision is available in Section 1.6.

other fisheries, such as Dungeness Crab and Albacore Tuna. From 2004 to 2013, the highest value in ex-vessel revenues was $754,585 (2010) with a low of $102,257 (2013). Live spot prawns can earn $10 per lb and greater. It has also become popular to sell "prawn tails" directly to the public during summer. Primary ports for spot prawn landings include Westport, Seattle, Neah Bay, and Port Angeles, with Grays Harbor (Westport) accounting for an average of 87% of fishery revenues from 2004-13 (Industrial Economics Inc., 2014).

Razor Clams

The commercial razor clam fishery occurs from May through June each year and harvest is limited in Washington to the detached spits at the mouth of Willapa Bay in Pacific County, accessible only by boat. Unlike other commercial fisheries, vessels are not used in the actual harvesting. The majority of commercial razor clam catch is sold as bait for the Dungeness Crab fishery. In 2015, 132 commercial razor clam licenses were issued by WDFW, and 122 of those license holders were residents of Pacific and Grays Harbor County.

Razor clams are landed exclusively in Pacific County and Grays Harbor, with Pacific County averaging large majority of revenues. Total harvest has ranged from a low of 102,900 lbs to a high of 281,900 lbs between 2004 and 2014. Total revenue has ranged from a low of $182,390 to a high of $588,620 between 2004 and 2014.

Pacific Halibut

The commercial harvest of Pacific Halibut takes place in an open access directed commercial fishery and through an incidental retention allowance of halibut in the fixed gear sablefish fishery north of Point Chehalis and for the salmon troll fishery coastwide. Due to the derby nature of the fishery and recent increases in effort, the directed commercial fishery only lasts a few days. When open, the directed fishery is only open south of Point Chehalis. Participation varies depending on the timing and availability of other fishing opportunities.

Hagfish

Hagfish (aka slime eels) began as a commercial fishery in 2005 and operates off Washington and Oregon. It remains as one of the state's few open access fishing opportunities with licenses available to anyone wanting to participate. There have been between 15 and 20 licenses in circulation, with fewer than 3 to all 15 active in any given year. This fishery is open year-round, and operates via pot gear on muddy or sandy bottom between depths of 300 to 480 feet (50 to 80 fathoms), as it is prohibited in waters shallower than 300 feet. The market is extremely volatile with almost all of the product going to Korea. The voluminous slime produced by hagfish makes the fishery a difficult one as well. Westport is a key landing port, and landings are also made in Ilwaco, Port Angeles, Port Townsend, and Blaine. Landings, the price-per-lb, and total revenue in Washington have increased steadily since the fishery started, with ex-vessel values reaching a historical high of about $2.27 million in 2012.

Recreational Fisheries

This section describes the major recreational fisheries occurring within the MSP Study Area. Fisheries managers typically classify recreational fisheries based on the species or species groups being targeted, but again, they may be classified and categorized differently for different management purposes. Table 2.4-7 lists the categories used here and the average number of angler trips associated with each. Unlike most commercial fisheries, recreational fisheries are open to anyone wishing to participate and a single fishing license authorizes anglers to participate in all MSP Study Area fisheries. A single fishing trip might cover what are described as separate fisheries (e.g., salmon and bottomfish “combo” trip). The full diversity of fishing opportunities, seasons, and rules can be viewed in in the Sport Fishing Regulation Pamphlet published by WDFW each year (Washington Department of Fish and Wildlife, 2016).

The major categories described here include salmon, groundfish (called “bottomfish” in state fishing regulations), Pacific halibut, Albacore Tuna, and Razor Clams. With the exception of razor clam harvests, which take place on the beach, the major recreational fisheries discussed here are conducted on boats on the open ocean, as well as inside the estuaries[12] for certain species like salmon. Anglers also fish from shore for species like Redtail Surfperch, and from jetties for species like Lingcod, yet these activities are not discussed in detail here. Likewise, while the focus in this section is on the fisheries happening within the MSP Study Area some fishing trips cross over into the Strait of Juan de Fuca or Columbia River Estuary.

The core information on the recreational fisheries of the MSP Study Area is collected by WDFW’s Ocean Sampling Program (OSP). Using a survey sampling design, WDFW staff counts vessels active in the major ports and sample the catch from a portion of them on random days of the week. This information on fishing effort (“angler-trips”) and catch are then used to estimate the total effort and catch for each month of the year. The estimates of catch and effort are publically available together with those from Oregon and California through the PSMFC’s RecFIN database. OSP focuses primarily on the boat mode but also samples anglers fishing from certain jetties.

Boat-based recreational fishing has two distinct components: a charter boat, “for-hire” fleet carrying paying passengers and a “private boat” fleet where anglers fish aboard vessels they rent or own. Over the past decade, charter vessels carried approximately 32% of anglers making fishing trips and 66% are taken on private vessels on average (Table 7). Charter boats and private vessel activity varies by species caught and port location. Westport and Ilwaco have had the largest charter boat operations (Table 7).

The Washington charter boat industry has been a major part of coastal communities for decades. The industry developed rapidly after World War II, focusing exclusively on salmon through the 1960s and Westport billing itself as the “Salmon Fishing Capital of the World.” The number of charter vessels peaked in 1977 but between 1977 and 1984, there was a rapid decline due to major changes in salmon management and abundance. Those remaining in the business diversified their portfolio of trips and began out new opportunities for bottomfish, Albacore, and eventually Pacific Halibut. Charter boat activity has been relatively stable since the 1990s, but remains below the historical peak (Industrial Economics Inc., 2014).

A survey of the charter boat industry indicated that 100% of the charter boat crew, owners, and guides/skippers were Washington coast residents. Charter boat clients out of the Westport area are estimated to be comprised of between 85% and 95% Washington residents, whereas 45% of clients out of the Ilwaco area were estimated to be Oregon residents, 45% residents from inland Washington counties, 5% from the Washington coast, and 5% from other areas (Taylor et al., 2015). On average, over half of the current charter boat trips target salmon, with bottomfish representing the next most frequently targeted species group (Table 8). The average number of charter boat trips annually has decreased by about 8% when comparing trips made during the 2009-2013 period with the number of

[12] Recreational fishing occurs in Willapa Bay and Grays Harbor estuaries. However, while maps were able to be produced for recreational fishing activities in the ocean, spatial data for recreational fishing in the estuaries were unavailable. Therefore, the State is unable to provide maps showing recreational fishing in the estuaries.

trips made between 2004 and 2008. Comparing those same time periods, the number of trips targeting Pacific Halibut, salmon, and bottomfish have declined while Albacore trips have increased.

Table 2.4-5. Sport fishing effort by trip mode 2004-2013 average for all coastal Washington port areas. Source: Ocean Sampling Program, WDFW as reported in (Taylor et al., 2015)

Mode of Fishing Trip	Westport	Ilwaco	Neah Bay	La Push	Chinook	All Areas
Charter boat	32,695	10,171	3,131	1,144	48	47,188
Private boat	20,020	26,181	29,754	7,051	15,416	98,420
Jetty[13]	-	-	-	-	-	1,783
Total[14]	52,711	36,351	32,881	8,192	15,461	147,389

Table 2.4-6. Charter boat fishing effort by targeted species 2004-2013 annual average for all coastal Washington port areas. Source: Ocean Sampling Program, WDFW as reported in (Taylor et al., 2015)

Targeted Species	Average Annual Number of Trips	Percent of Total
Albacore	1,707	4%
Bottomfish	13,877	29%
Halibut	4,976	11%
Salmon	26,555	56%
Other	74	<1%
Total	47,188	100%

Private vessel anglers launch, on average, primarily from Neah Bay (30%), Ilwaco (27%), and Westport (20%) (Table 2.4-7). The smaller ports of La Push and Chinook also offer a limited number of slips for private boats as well as boat launches. No data are currently available that identify the county of residence of private boat anglers fishing in ocean waters off the Washington coast. Overall, private boat trips have increased by about 11% when comparing the number of average annual trips made between 2009 and 2013 with average annual trips made between 2004 and 2008. Targeted species with the largest increases in trips were salmon, albacore, and bottomfish. More than 74% of trips taken by private vessels target salmon (Table 2.4-9). Cascade Economics (Taylor et al., 2015) reports a recent trend toward larger private vessels capable of traveling farther offshore.

Table 2.4-7. Average annual private vessel fishing effort by targeted species 2004-2013 for all coastal Washington port areas. Source: Ocean Sampling Program, WDFW as reported in (Taylor et al., 2015)

Targeted Species	Average Annual Number of Trips	Percent of Total
Albacore	2,621	3%

[13] North Bay jetty area of the Columbia River.
[14] Totals may not add to 100% due to rounding

Bottomfish	13,254	14%
Halibut	7,844	8%
Salmon	73,018	74%
Dive	397	<1%
Other	1,285	1%
Total	98,420	100%

Shore and jetty based anglers primarily fish from the Columbia River Jetty near Ilwaco. In 2013, 3,467 trips were recorded by anglers here, substantially higher than the 2004-2013 annual average of 1,783 trips. An estimated 87% of the fish caught by jetty anglers in 2013 were salmon, with rockfish making up the remainder (Taylor et al., 2015).

Sport catch (a.k.a. the number of fish caught or clams dug) by species group is shown in Table 2.4-10. Catch, trends, and management for each species group are discussed below.

Table 2.4-8. Average annual sport catch in marine waters[15] along the Washington coast 2007/2008 through 2011/2012 sportfishing seasons. Source: WDFW as reported in (Taylor et al., 2015).

Species Group	Average Annual Number Caught[16]
Salmon[17]	105,077
Sturgeon[18]	378
Pacific Halibut	7,613
Bottomfish[19]	277,912
Razor Clams	3,129,482

Salmon

The recreational salmon fishery occurs in Willapa Bay, the Chehalis Basin (Grays Harbor, Humptulips River, and Chehalis River), and the Pacific Ocean (Industrial Economics Inc., 2014). Ocean salmon are the most popular finfish target species for effort (Table 2.4-8 and Table 2.4-9), and the second highest in terms of average catch between 2007 and 2012 (Table 2.4-10). Salmon catch has been relatively inconsistent in recent years, with the lowest number of fish caught (37,272 fish) in the 2008/09 season and the highest number (221,205 fish) in the following season (2010/11).

During the 2011/12 fishing season, about half of all salmon caught in the Study Area occurred off Westport (WDFW Marine Area 2), about 25% were near the Ilwaco area (WDFW Marine Area 1), and about 12% caught in the area near Cape Flattery (WDFW Marine Area 4a). The species of salmon caught

[15] Marine areas include coastal streams, which are outside of the MSP Study Area.
[16] Numbers represent the number of fish caught or clams dug.
[17] Salmon totals include all species, including coho and Chinook.
[18] Sturgeon total includes only fish caught in coastal streams.
[19] Bottomfish include all rockfish species and other bottomfish.

also varies by area, with about half of all Chinook salmon landed in Westport, and about three quarters of all pink salmon caught being landed in Neah Bay (Taylor et al., 2015). Westport and Ilwaco both strongly and equally represent fishery harvest during 2003-2013, a period of inconsistent effort and catch. High and moderate areas for ocean salmon fishing are shown in Map 25. The coastal estuary recreational salmon fishery has also been inconsistent from 2003-2012, with a high of 33,109 fish caught in 2012. Grays Harbor accounts for about 60% of the fish caught (Industrial Economics Inc., 2014).

Salmon recreational fisheries off the coast of Washington are managed by WDFW with management coordinated with PFMC and co-managed with the tribes. Because of the migratory behavior of salmon, management is a complex process. FMPs are in place for salmon because some evolutionary significant units are listed under the Endangered Species Act. Most of the Chinook salmon caught, however, are of hatchery origin, largely from hatcheries in nearby coastal streams as well as in the Columbia River and Puget Sound. Marine recreational fishing regulations for salmon include daily limits, release rules, minimum size, and season dates, all of which vary by Marine Catch Area.

Bottomfish

The recreational bottomfish fishery represents the largest recreational finfish fishery by average number of fish caught annually (Table 2.4-10). The bottomfish fishery is also the second most popular finfish recreational fishery in terms of number of trips taken for targeted species for both charter boat and private boat fishing (Table 2.4-8 and Table 2.4-9, respectively). Primary targets within this fishery are rockfish and lingcod, with Black Rockfish being the main target. Other bottomfish species targeted or kept include lingcod, cabezon, kelp greenling, and Pacific cod. While the season has been open year-round, weather typically limits fishing to March through October. Westport, Neah Bay, and La Push are the primary ports for this fishery. Westport sees the greatest amount of recreational bottomfish fish caught, consisting mostly of Black Rockfish while Neah Bay has a much higher diversity of rockfish species caught, including China, Quillback, and Copper Rockfish. Westport supports most of the charter trips, and Neah Bay hosts the majority of private vessels. The fishery has been relatively stable over time (Industrial Economics Inc., 2014; Taylor et al., 2015). High and moderate recreational fishing activity in the MSP Study Area for bottomfish are shown in Map 26.

Pacific Halibut

The recreational Pacific Halibut fishery occurs from May through September. It is a quota limited fishery that lasts only four to five days per year in the most popular areas on the coast. The fishery has been relatively stable since 2003 (Industrial Economics Inc., 2014), with a five year average from 2007/08 to 2011/12 of 7,613 fish caught per year (Table 2.4-10). The north coast ports of Neah Bay and La Push accounted for about twice the number of angler trips for halibut during the 2011/12 season than along the south coast (Taylor et al., 2015). Neah Bay and La Push have also consistently had recorded the large majority of recreational halibut harvest over the past decade (Industrial Economics Inc., 2014). High and moderate recreational fishing in the MSP Study Area for halibut are shown in Map 27.

Both private and charter vessels participate in this fishery, but the fishery favors larger vessels since it occurs fairly far offshore. Managers have noticed an increase in private vessels participating in this fishery, growing from about equal participation between private and charter vessels in 2004 and 2005, to double the number of trips made by private vessels than charter vessels in the 2013 season (Industrial Economics Inc., 2014).

Washington coastal Pacific Halibut fisheries are managed under the PFMC's Pacific Halibut Catch Sharing Plan (CSP) for Area 2A (Norman et al., 2007).[20] The CSP specifies how the Area 2A total allowable catch, as defined by the International Pacific Halibut Commission, is allocated or "shared" among various state commercial and recreational fishing interests. WDFW manages its recreational fisheries by three subareas: North Coast, South Coast, and Columbia River. The fishery is managed through quotas, and is monitored regularly to close or extend the fishing season as appropriate (Taylor et al., 2015).

Albacore Tuna

Albacore Tuna is a popular recreational fishery along the Washington coast during the summer and early fall when the fish migrate into the area. As with the commercial fishery, the fish tend to be available between 20 and 100 nautical miles offshore (Map 28). Albacore are caught using jigs, which are trolled behind the vessel, as well as with live bait while drifting. Albacore are targeted by both charter boats and private vessels. The average number of total albacore trips from 2004-2013 was 4,328 (Table 2.4-8 and Table 2.4-9). Substantial increases in albacore private boat fishing activity for albacore occurred in 2013, with 7,056 private vessel trips. Westport and Ilwaco are the main ports for this fishery.

Razor clam

The coastal beach-beach based razor clam fishery is an extremely popular recreational fishery along the Washington coast. Razor clam recreational harvesting, cleaning, cooking, eating, and canning have been an important focus of family relationships and local culture in Washington State coastal communities for many generations. With between 275,000 and 460,000 seasonal digger trips harvesting as many as 6.1 million clams, the fishery generates between $25 and $40 M in tourist related income to the economies of the rural coastal communities along the MSP Study Area. About 70% of the fishery harvest occurs along the Long Beach and Twin Harbors areas. Recent years (2013 and 2014) have seen a marked increase in fishery participation and clams dug. The number of clams dug is highly correlated with the number of digger trips. Razor clamming occurs along the southern Washington coast south of the Quinault Indian Reservation to the mouth of the Columbia River and at Kalaloch[21] (Map 29).

Active state management of the razor clam fishery began in 1929 with a daily bag limit of 36 clams per person and no season. Over the years, clamming seasons have been established and daily bag limits have been adapted based on razor clam population assessments. Also, starting in 1993, governments of coastal tribes began to exercise treaty fishing rights for shellfish and since that time razor clam beaches north of Point Chehalis have been co-managed through state and tribal fishery management agreements. Opening of tribal fisheries (commercial, ceremonial, and subsistence) are timed to avoid conflicts with the state recreational fishery openers. At present, with stable populations, the state recreational season starts with the first good tide series in October with sporadic openings each month, depending on the numbers of harvestable clams by area, ending in early to late May. The state (WDFW) recreational daily bag limit is 15 clams per person. Occasionally, long-term area closures of both state and tribal razor clam fisheries have occurred in response to large scale population declines or human health factors. Recently, closures have been due to increases in levels of naturally occurring marine biotoxins (caused by blooms of harmful algae), which can significantly disrupt these fisheries.

[20] Area 2A is comprised of the area off the coasts of Washington, Oregon, and Northern California.

[21] Kalaloch beach is located within the Olympic National Park and the recreational razor clam fishery at this beach is jointly managed by the Olympic National Park and WDFW.

Dungeness Crab

Dungeness Crab is one of the most popular recreational fisheries in the state, mainly in Puget Sound. However, relatively little activity occurs within the Study Area with most coastal activity limited to Willapa Bay, Grays Harbor, and the Columbia River. There has been a recent increase in the number of recreational crabbers who hire charter boats to participate in the fishery prior to the opening of the commercial fishery. The recreational Dungeness Crab harvest is managed by WDFW. However, WDFW does not require reporting of recreational harvest along the coast and therefore data on landings or the number of harvest trips are unavailable.

Tribal Fisheries

The coastal tribes have been engaged in fishing throughout their history. Fishing is an integral part of the history, culture, identity, economy, and future of the coastal tribes. Each tribe participates in and relies on fishing for jobs and income within their communities as well as for ceremonial purposes and subsistence. As noted in the introduction to this Chapter, many tribal fisheries use the same or similar techniques and deliver their catch to many of the same markets as state and federally licensed commercial fishermen. For sake of terminology however, this Chapter refers to them as tribal or treaty fisheries to indicate that they are managed under separate authorities held by the tribes. Ceremonial and subsistence fishing are distinguished where appropriate.

The four coastal treaty tribes: Makah, Quileute, and Hoh Tribes, and the Quinault Indian Nation are co-managers of the fisheries resource with fellow tribes, the state of Washington, and/or federal agencies. These tribes have reserved treaty rights to 50% of the harvestable fish and shellfish occurring within the coastal treaty area to harvest within their usual and accustomed areas (U&As). These treaty tribes also participate in the PFMC process and are represented by a tribal seat so that decisions for non-treaty fisheries are reflective of tribal fishery management decisions. Tribal fisheries are not negotiated through PFMC (see Section 1.6 Pacific Coast Indian Tribes and Treaty Rights). The tribal fisheries profile below summarize available information on fishing activities and economic impacts for each of the four coastal treaty tribes.[22]

Makah Tribe

Fisheries are an important component of the Makah Tribe's livelihood and economy. Makah tribal fisheries include 20 different fisheries based on species, gear types, and season, including five species of salmon, groundfish, and shellfish (Table 2.4-11). The salmon gillnet fishery occurs along the shore near Cape Flattery and in the Strait of Juan de Fuca, other fisheries occur offshore off the north coast of the Olympic Peninsula within the MSP Study Area (Taylor et al., 2015).

Table 2.4-9. Makah tribal fisheries

Mid-water (Pacific whiting, yellowtail rockfish)	Bottom trawl (cod, flatfish)
Longline (halibut, black cod/sablefish)	Ocean troll (Chinook and coho salmon)
Summer strait (Chinook salmon)	Winter strait (Chinook salmon)

[22] Information related to the Shoalwater Bay Tribe fishing activity is not included.

Drift gill net (sockeye, chum, and pink salmon)	Set gill net (Chinook salmon)
Dive fisheries (shellfish, sea cucumber, sea urchin)	Dungeness crab (ocean and Strait of Juan de Fuca)
River set net/hook-and-line (salmon)	Tuna
Hagfish (in development)	

As of 2011, about 188 tribal fishing vessels were estimated to operate out of Neah Bay. The estimated annual, average ex-vessel value for all Makah tribal fisheries between 2007 and 2011 was about $6.5 million. The majority of ex-vessel value comes from the groundfish fishery (Table 2.4-12). This value does not include the catch by tribal fishers other than that delivered to Neah Bay. The Makah tribe also participates in the Pacific Whiting fishery, which is either processed at sea or delivered to Westport, so the ex-vessel values reported in the table understate the total Makah tribal fishery ex-vessel value (Taylor et al., 2015).

Table 2.4-10. Estimated ex-vessel value of tribal fishery landings in Neah Bay: Average of 2007-2011 (2014 dollars). Source: (Taylor et al., 2015).

Fishery	2007-2011 Average Ex-Vessel Value
Groundfish	$4,330,000
Salmon	$1,887,000
Shellfish	$197,000
Other	$62,000
Total	$6,476,000

Quileute Tribe

Fishing is a mainstay of the life and economy of the Quileute Tribe; nearly every family on the Quileute Reservation has members involved in fishing. Crab, salmon (steelhead, coho, and Chinook), black cod (sablefish), and Pacific halibut are the majority of the catch. Other species include tuna, sea cucumber, certain rockfish, and other groundfish, such as lingcod (Table 2.4-13). The tribe has shown growing interest in Pacific whiting. The tribe has an agreement with a non-tribal processor, High Tide Seafood of Port Angeles, as a buyer for their catch in La Push. Total revenue from Quileute fisheries in 2014 was estimated at about $1.1 million, and ranged from $1.1 million to $3.6 million from 2005-2014 (Taylor et al., 2015).

The tribe regulates its own fishery and sets season length, catch, and other restrictions, this information is then shared with other co-managers. The Dungeness crab fishery is of particular importance to the tribe. The crab season typically begins in November and runs through October, but this can vary. Pursuant to a court case decided in 2005, agreements with the state include “Special

Management Areas". These areas are annually negotiated with the co-managers and provide the tribe with an exclusive area for the opportunity to harvest as non-tribal fleets have a much larger capacity.[23]

Table 11. Quileute tribal fisheries 2014 harvest and annual range from 2005-2014* by species (thousands of lbs). Source: (Taylor et al., 2015).

Species	2014 Harvest	Annual range from 2005-2014[24]	
		Low	High
Crab	65	65	1,184
Black cod	42	7	97
Halibut	12	6	54
Groundfish	33	1	58
Chinook	66	28	66
Coho	279	120	777
Steelhead	28	21	76
Other	0	0	12
Total	525	-	-

Hoh Tribe

The Hoh Tribe is dependent economically, culturally, and spiritually upon fisheries within the tribe's U&A, and the tribe places considerable emphasis and resources on the management and protection of its U&A fisheries. Although the tribe does not have a port or marina on the reservation, a high proportion of tribal members participate in, and are dependent upon, the treaty salmon fishery. No public information is available about the Hoh Tribe's treaty harvest or ex-vessel revenues (Taylor et al., 2015).

Quinault Indian Nation

The Quinault Indian Nation regulates several tribal treaty fisheries within their usual and accustomed treaty harvest area that includes three major river systems (Queets, Quinault, and Chehalis/Humptulips), Grays Harbor, and a large ocean area. Fisheries include gillnet for Chinook, coho, sockeye, chum salmon, steelhead, and white sturgeon; ocean troll for Chinook and coho salmon; marine fisheries for halibut, sablefish, lingcod, rockfish, and sardines; Dungeness crab; and razor clams

[23] The specific elements of state-tribal agreements may change from year to year. WDFW issues Letters to Fishers announcing the agreed to management measures on its website before the start of each season at: http://wdfw.wa.gov/fishing/commercial/crab/coastal/letters_notices.html

[24] Data from 2010 is not included

harvested from the beaches. According to the Quinault Department of Fisheries, the average number of vessels to participate per year from 2004 to 2013 was 35, with 22 of those being crab vessels. The average number of treaty fishers and helpers participating per year during that period was 159. The 2004-2013 annual average ex-vessel revenues from Quinault treaty fisheries was about $9.2 million (Table 2.4-14). Dungeness crab represents the largest proportion of theses revenues, highlighting the crab fishery's economic importance to the tribe. Recent years have shown the highest crab fishery revenues, indicating the continued and growing importance of this fishery (Taylor et al., 2015).

Quinault continues to develop other treaty fisheries within its ocean U&A including Pacific whiting, tuna, hagfish, spot prawns, pink shrimp, and others.

Table 2.4-12. 2004-2013 Annual ex-vessel revenues from Quinault treaty fisheries (2014 dollars). Source: (Taylor et al., 2015).

Fishery	Total
Grays Harbor gillnet	$654,000
Ocean salmon troll	$71,000
Marine fish	$1,066,000
Dungeness crab	$6,794,000
Razor clam	$637,000
Total fisheries	$9,223,000

Economic Impact of Commercial and Recreational Fishing

Commercial and recreational fisheries target and create economic benefits from many of the same Study Area fish and shellfish populations. This section describes the different manner in which commercial and recreational fisheries produce those benefits and summarizes their estimated economic contributions to the coastal and state economies. The estimates were produced by the Cascade Economics study (Taylor et al., 2015) and are based on information from 2014. While 2014 provides a baseline that is reflective of the general magnitude of the economic contributions made by commercial and recreational fisheries in the MSP Study Area, actual economic contributions should be expected to vary from year to year based on a number of factors ranging from fluctuations in fish populations to changing conditions in the global economy. For a further explanation of the models used to estimate the economic contribution of MSP Study Area fisheries, please see Section 2.3 Socio-economic Setting and the Cascade Economics report.

The economic benefits of commercial fisheries arise as fishers attempt to profit by entering their catches into commerce through sale, barter, or trade and seafood businesses seek to add value by processing and facilitating transactions with restaurants, retailers, and other consumers and users of fish and shellfish products. The revenues earned by fishing operations and seafood businesses are the "direct" economic input to the state and coastal economies.

The money fishing operations earn for their catch is referred to as ex-vessel revenues. Ex-vessel revenues are what fisheries management agencies typically use to report the economic size of a fishery.

However, ex-vessel revenues are just part of the economic activity generated by a fishery as their effect is multiplied as they move between links in the economy. For example, fishing businesses use ex-vessel revenues to purchase goods and services used in their operations and to pay income to owners and crew. The spending for things like fuel, boat repair and maintenance, gear and supplies, etc. leads to “indirect” effects on the economy as the businesses providing these goods and services turn around and spend on portion of the revenues on expenses and income. A third type of effect, called “induced” effects, happens as owners and employees from fishing and supporting businesses spend their disposable income throughout the economy.

Seafood buyers and processors are the next direct link in the economic chain. Although some fishing operations sell their catch directly to the public at the dock, and some processing businesses own and run their own fishing vessels, most fishing operations landing in the state sell their catch to another seafood processing or distribution business. Fish and shellfish from the MSP Study Area are sold into a diverse set of markets, including for: direct human consumption at restaurants and retail stores, pet food, fertilizer and feed in various agriculture and aquaculture operations worldwide, and more. These markets are what give commercial value to the fish and shellfish and the source of the ex-vessel revenues seafood businesses pay to fishing operations.

On top of paying ex-vessel revenues, the businesses first receiving fish and shellfish landings create other indirect and induced effects. The degree to which these effects contribute to the state and coastal economies varies. In other words, a dollar of ex-vessel revenue can translate to a much different total economic contribution depending on several factors. For instance, some of the catch goes to large processing facilities located in port that provide substantial employment opportunity to local residents. Other catch requires minimal labor to prepare for market and so may have a lower total economic contribution because of the lack of jobs supported. As another example, some landings are transferred from the fishing vessel straight onto a truck and quickly transported to a processing facility in Oregon. The economic contribution of this landing could be of equal size to the first example, but much of it would “leak” from the state’s economy and so be less beneficial to the coastal counties. However, the reverse also happens with some landings of seafood in Oregon being transported to Washington for processing.

Using their model of the economic linkages[25] outlined above, Cascade Economics estimated that commercial fishing and primary seafood processing had a total economic contribution of 1,820 jobs and $77.2 million in labor income in the coastal counties (Table 2.4-15) and 2,830 jobs and $117.0 million statewide (Table 2.4-16) in 2014. This total economic contribution is based on over 129 million lbs of fish and shellfish and $93 million in ex-vessel revenues reported to WDFW in 2014.

While these estimates capture a core portion of economic activity related to Washington’s commercial seafood industry, they are not intended to be comprehensive. For instance, the estimates do not include the effects of secondary processing activities (e.g., fish oil or fishmeal produced as byproducts of primary processing), the effects from additional distribution and retailing of the seafood landed in the coastal counties, or activities related to imports or fish caught in Alaska. In addition, the estimates do not cover catch from the Study Area that are landed into Oregon or Puget Sound, or the harvesting and processing activities of the Puget Sound based at-sea whiting sector. While no estimate was made for landings into Oregon, Cascade Economics estimated Puget Sound landings contributed an additional $2.3 million in income and approximately 60 jobs in the coastal counties, with an additional $8.2 million in income and approximately 190 jobs statewide. They also estimate that the Puget Sound

[25] The economic multipliers used were derived using IMPLAN models based on 2012 regional economic data.

based at sea whiting processing vessels contribute an additional 220 jobs and $15.8 million in labor income to the state.

Lastly, Washington's commercial fishing and seafood industries have strong ties to the fisheries of Alaska as well as to fish and shellfish imported from elsewhere. Additional information about the economic linkages between Washington's fishing communities and commercial fishing in other areas can be found in the Cascade Economics (Taylor et al., 2015) report.

Table 2.4-15. Total contributions to the five-county[26] coastal region economy from 2014 Washington coast non-tribal commercial fishing and seafood processing by county of the activity. Source: (Taylor et al., 2015)

	Coastwide	Clallam County	Grays Harbor County	Pacific County	Wahkiakum County
Income ($ mil.)	77.2	2.3	50.3	23.7	0.9
Jobs	1,820	70	1,080	610	60

Table 13. Total contribution to the State of Washington economy from Washington coast non-tribal commercial fishing and seafood processing by county of the activity. Source: (Taylor et al., 2015)

	Coastwide	Clallam County	Grays Harbor County	Pacific County	Wahkiakum County
Income ($ mil.)	117.0	3.4	75.8	36.6	1.2
Jobs	2,830	120	1,700	950	60

In contrast to commercial fishing, recreational fishing is conducted for sport, enjoyment, or personal use, and state law prohibits anglers from selling their catch. It is the willingness of anglers to spend income to make fishing trips in the Study Area that provides the direct economic input to coastal and state economies. These "trip related expenditures"—on things like fuel for vehicles and boats, fishing gear and supplies, lodging, food at grocery stores and restaurants, bait, charter boat fees, etc.—that also produce indirect and induced economic benefits as revenues earned by businesses that provide goods and services to anglers, and the income earned by owners and employees of these businesses are spent throughout the economy.

Recreational trip related expenditures provide another example of how the location of spending matters to where economic benefits are received. Anglers traveling into the coastal economies from elsewhere produce extra benefit by injecting new money into the local economy. On the other hand, anglers may make a significant portion of the trip-related expenditures at home, benefiting the economy there instead of in the coastal economy. The charter boat industry is a distinct portion of the recreational fishing sector and the one that is also considered as a fishery sector. Owners and crew receive trip related expenditures that in the form fees and tips that anglers pay when taking trips aboard charter vessels. Because, as reported by Cascade Economics (Taylor et al., 2015), 100 percent of the

[26] There were no non-tribal commercial fisheries landings recorded in Jefferson County in 2014.

owners and crew reside in the coastal counties, a relatively high proportion of their spending is thought to remain in and benefit the coastal economy.

Using 2014 as a baseline, Cascade Economics estimated that anglers taking trips to fish in the MSP Study Area made $30.4 million in trip related expenditures in the coastal area and $40.9 statewide (Table 2.4-17). This spending translates to an overall economic contribution of 325 jobs and $17.3 million in labor income within the coastal economy and 596 jobs and $32.3 million statewide (Table 2.4-18). Labor income includes money and benefits paid to employees as well as the earnings of owners and the self-employed. Of note, these estimates do not include purchases of equipment or durable goods such as fishing boats, boat trailers, or the vehicles needed to haul them. Such purchases certainly increase the level of recreational fishing's economic contribution to the state and coastal economies yet Cascade Economics reports that they are very difficult to estimate accurately.

Table 2.4-1714. Trip-related expenditures associated with ocean sportfishing trips in 2014 from charter vessels, private vessels, and shore and jetties in the Washington coastal region (2014 dollars). Source: (Taylor et al., 2015).

	MSP Study Area/Coastal Spending	Spending Elsewhere in WA	Total Spending in WA
Charter vessels	$15,770,540	$3,865,590	$19,636,130
Private Vessels	$14,416,219	$6,416,963	$20,833,182
Shore and Jetty	$256,964	$160,641	$417,606
Total	$30,443,723	$10,443,194	$40,886,917

Table 2.4-18. Contribution of trip-related angler expenditures in the MSP Study Area/Coastal Area to coastal area and statewide employment and labor income. Source: (Taylor et al., 2015).

	MSP Study Area/Coastal Area	Statewide
Contribution to Employment	325	596
Contribution to Labor Income	$17,327,751	$32,338,444

Related Infrastructure

Ports and marinas

The state's fishing industry operates from several ports located adjacent to the Study Area as well as in the Strait of Juan de Fuca and inside Puget Sound. These ports provide infrastructure like moorage and access (e.g. via boat ramps) for commercial and recreational fishing vessels, gear and boat maintenance opportunities, and are the site of fish buying and processing activities. Below are brief descriptions of commercial and recreational fishing activity by port to highlight key coastal locations and communities connected to fishing. Tribal fisheries are not included in the statistics reported in this section but they do operate out of many of the same ports and depend on the same infrastructure. A map of MSP Study Area ports and adjacent ports is provided in (Map 30). Additional discussion of Ports is in Sec. 2.7 Marine Transportation, Navigation, and Infrastructure.

Clallam County ports

Neah Bay

Neah Bay is the largest commercial fisheries port in Clallam County and is also home of the Makah Tribe's fishing fleet, who own the fishing dock. It has had the greatest buyer participation, vessel participation, and landed ex-vessel revenues in the county for most years. Recently (2010-2014), there have been about seven buyers and 40 vessels operating out of Neah Bay. Total ex-vessel revenues from landings in the port in 2014 were about $1.1 million, the fourth largest in terms of ex-vessel revenues landed in Washington coastal ports.

Neah Bay also serves as an important marina for recreational fishing. Over 3,000 average annual charter boat trips were taken from Neah Bay during 2004-2013, and almost 30,000 average annual trips were taken by private vessels during that same time period (Table 2.4-7). Neah Bay serves as the primary private boat marina supporting the most average annual private vessel trips along the Washington outer coast. Salmon, Pacific Halibut, and bottomfish are popular targets from this marina (Taylor et al., 2015).

La Push

The port in La Push is owned and operated by the Quileute Tribe, yet the port also supports non-tribal commercial and recreational fisheries. The port has a seafood processing plant on location. Data confidentiality limits the fishing reporting in La Push for some years. Recent available data indicate that about six buyers and 33 vessels operate in the port. Total ex-vessel revenues from landings in the port for 2014 were about $0.9 million, the fifth largest in terms of revenue landed on the Washington coast. About 1,600 recreational trips originated from La Push in 2014, with an average of 1,144 charter boat trips on average per year from 2004-2013. The annual average number of private vessel trips from La Push was about 7,051 during that same time period (Table 2.4-7). Recreational fishing trips target bottomfish, salmon, Pacific Halibut, and tuna (Taylor et al., 2015).

Jefferson County Ports

There have been no non-tribal commercial fisheries landings recorded in Jefferson County ports along the outer Washington coast since 2007. In previous years, fewer than three buyers and fewer than six vessels were operating there (Taylor et al., 2015).

Grays Harbor County Ports

Westport

Westport is the largest commercial fishing port on the Washington coast in terms of number of buyers, number of vessels, and total ex-vessel revenues generated from landings. Approximately 30 buyers and 300 commercial vessels have been operating in the port in recent years. Total ex-vessel revenues for landings in 2014 were $59.7 million, more than twice the value of the next largest port on the Washington coast (Taylor et al., 2015). Westport also ranks among the most important commercial fishing ports in country. Considering landings 2014, Westport was ranked 13th by landed weight (100 million lbs) and 14th by landed value ($64 million) for commercial ports in the United States (National Marine Fisheries Service, 2015).

Westport is also the most popular port for recreational charter fishing on the Washington coast. About 35 recreational charters operated from the port recently, fishing for salmon, groundfish, Pacific Halibut, and tuna. About 38,500 charter angler trips were taken from Westport in 2014, with an annual average of 32,695 trips during 2004-2013 while approximately 20,020 average annual private vessel trips were taken during that same time period (Table 2.4-7) (Taylor et al., 2015).

Pacific County Ports

Willapa Bay

In recent years, about 10 buyers and more than 100 vessels have been operating out of Willapa Bay ports. The main ports within Willapa Bay ports include South Bend and Tokeland. Total ex-vessel revenues from commercial landings in 2014 were about $4.8 million, the third largest in terms of value on the Washington coast. Salmon is the primary target for commercial fisheries, although anchovies and crab are also fished in Willapa Bay (Taylor et al., 2015). Willapa Bay ports also support recreational fishing within the estuary.

Ilwaco and Chinook

Ilwaco is the largest port in Pacific County and the second largest commercial fishing port on the Washington coast in terms of number of buyers, number of vessels, and total ex-vessel revenues generated. About 13 buyers and more than 200 vessels have been operating in the port in recent years. In 2014, total ex-vessel revenues paid for landings were $24.3 million, more than five times greater than the amount recorded in the next largest port, Willapa Bay (Taylor et al., 2015). The Ilwaco/Chinook port areas also rank among the most important commercial fishing ports in country. Based on landings in 2014, Ilwaco/Chinook ranked 35th by landed weight (27 million lbs average) and 49th by landed value ($25 million) for commercial ports in the United States (National Marine Fisheries Service, 2015). Primary commercial fisheries landing in Ilwaco/Chinook target groundfish, salmon, Dungeness Crab, Albacore, and shrimp.

Popular recreational fisheries operating from the Ilwaco/Chinook area target salmon, albacore tuna and sturgeon. In Chinook, all charter boat trips ceased in 2009 while the average annual number of trips for private vessels out of Chinook was 15,416 (Table 2.4-7). In Ilwaco, 10,171 average charter boat trips were made per year during 2004-2013, with 26,181 average private vessel trips were made per year during that same time period (Table 2.4-7) (Taylor et al., 2015).

Data confidentiality restricts the availability of fisheries data for other Pacific County ports. In recent years, about 11 vessels were making landings in other Pacific County ports along the coast, and as high as 17 vessels landing in ports along the Columbia River (Taylor et al., 2015).

Wahkiakum County ports

A total of 72 vessels made landings in Wahkiakum County ports in 2014, with nearly $1 million in ex-vessel revenue. Between five and eight buyers were operating in these ports in recent years. Data from individual ports within the county were not available. Wahkiakum County ports deal almost exclusively with salmon landings (Taylor et al., 2015).

Future Trends

Future trends within the commercial and recreational fishery industries are difficult to predict. Several factors can have a significant influence on the participation and economics of these industries.

While no predictions can be made for certain, primary factors are summarized below to give insight to the future trends and challenges of these industries.

Barriers to participation in the commercial fishery industry

Initial entry into the commercial fishing industry can be quite costly. For example, the sector analysis completed by Industrial Economics, Inc. (2014) cited that between purchasing a crabbing vessel, permits, and gear, it could cost around $250,000 to $1 million to enter the Dungeness crab fishery. The younger fishing generation typically does not have access to this amount of money. In addition to the high initial costs to enter a fishery, the current trend of participating in multiple fisheries also means additional initial costs to obtain permits and gear types for each fishery. While a diverse portfolio increases the opportunities to earn income throughout the year, it also requires more money to be paid or borrowed before any actual fishing takes place, increasing risk. These financial barriers to entry and participation can create uncertainty around the future of fishing industries, particularly for locally based fishermen (Industrial Economics Inc., 2014; Taylor et al., 2015).

Regulatory uncertainty: commercial fishing and recreational fishing

Fisheries are a highly regulated industry and the primary management aim of long-term sustainability can sometimes be at odds with economic interests in the short-term. Estimates of sustainable catch levels can be highly variable because of uncertainty in the estimates and real fluctuations in the size of fish and shellfish populations even in the best monitored fisheries. Catch rates and fishing effort can be likewise variable. All in all, this variability and uncertainty makes it difficult for commercial and recreational fishing industries to make long-term business plans or to even rely on the forecasts for any given year. For example, if catch in-season reaches the quota for a limiting species like Yelloweye Rockfish, emergency closure of the groundfish fisheries could occur, which would cut the season short and create economic losses. Another example is the quota based recreational Pacific Halibut fishery, which concentrates the fishing season in some areas to a handful of days, yet the season may be extended for additional days if the quota is not caught. Under such circumstances, it is difficult for recreational charters, and the supporting hotel, restaurant, and other businesses that cater to recreational fishermen, to prepare for the influx of Pacific Halibut anglers (Industrial Economics Inc., 2014; Taylor et al., 2015).

Other examples of how regulations impact fisheries include the consolidation of the trawl fishery and the management of the Dungeness crab fishery. Increasing costs coupled with the retirement of vessels and permits from the fishery and buyback and nature of the trawl IFQ program has reduced the number of trawl vessels registered to Washington coastal residents. The Dungeness crab industry experienced a significant shift after the 1994 Rafeedie decision, which resulted in the co-management of the Dungeness crab fishery between WDFW and each of the four coastal treaty tribes and ultimately brought about the reduction of Washington crabbing grounds and fleet. The crab fleet has proven resilient and adjusted to the alterations of space, increased competition, and diversification. At the end of 2016, however, the Dungeness crab fishery management structure in where states manage the fishery, even in federal waters, expired, leaving the possibility for a different management regime.[27] Uncertainty in fisheries management and available quotas affects vessel owners and processors who may be considering making capital investments. Changing fisheries management policies and priorities

[27] This is an ongoing management issue with bills in both the Washington State House of Representatives and Senate at the beginning of 2017.

will likely continue to affect commercial fisheries in unexpected ways (Industrial Economics Inc., 2014; Taylor et al., 2015).

Environmental factors

As living, natural resources, fisheries are influenced by environmental conditions, which are frequently outside of human control. As noted in the previous section, natural variability in ocean conditions influences stocks from year to year and from fishery to fishery. A warming climate and changing water temperatures may influence fish stocks and fishery seasons, especially for species such as Albacore Tuna, Salmon, Dungeness Crab, Pacific Whiting, and Pacific Sardine. Although many species may be forced out of the area by warming ocean temperatures, other species may expand their range and open new opportunities for fisheries. Ocean acidification may also affect fisheries. Studies are currently investigating the impact of increased ocean acidity on juvenile Dungeness crab and several other fish and shellfish. Concerns also surround ocean acidification’s effect on important food sources for salmon (Industrial Economics Inc., 2014; Taylor et al., 2015).

Harmful algal blooms (HABs) also influence resource availability. Closures of razor clam beaches to protect human health due to HABs have a significant impact on recreational clamming and the coastal communities supporting the tourism that accompanies razor clamming trips. Recently, HABs have closed both recreational and commercial shellfish fisheries. In May of 2015, an extremely large HAB event occurred that affected the entire U.S. west coast. In Washington, all razor clam fisheries closed in May and most beaches did not reopen until sometime between late December 2015 and mid-February 2016. In early June, the southern half of the Washington coast (including the Columbia River and Willapa Bay) was closed to all Dungeness crab fisheries followed in early August by a closure of a substantial portion of the northern half of the Washington coast (including Grays Harbor). Most of this area remained closed to crabbing through September, the normal end of the commercial season (D. Ayres, WDFW, personal communication, August 4, 2016). Current speculations suggest that HABs may increase in the future as oceans warm and ocean acidity increases (Feely, Klinger, Newton, & Chadsey, 2012; Moore, Mantua, Hickey, & Trainer, 2010), potentially leading to more frequent razor clam and other shellfish closures.

Salmon production and survival

Salmon represent one of the most culturally and economically important fishery species in both the commercial and recreational sectors. However, many factors influence the salmon fishery including: oceanic conditions (which influence ocean survivability and spawning runs), predators (such as California sea lions at the foot of dams and Caspian terns on artificial islands), reductions in hatchery programs, habitat loss, fragmentation, pollution, and overfishing. Due to the complex nature of salmon life histories, as well as human history with salmon, the future of this fishery will likely continue to be dynamic and unpredictable (Industrial Economics Inc., 2014; Taylor et al., 2015).

Seafood markets

World markets can have a profound effect on the supply, demand, and distribution of seafood products. Exchange rates, political events, and overseas demand can influence demand for those Washington seafood products that rely on foreign markets. Some of these market forces can significantly influence profitability almost overnight. Overseas markets for Sablefish and Dungeness Crab are particularly influential. Market volatility will likely continue to be a major source of uncertainty in the commercial fishing economy (Taylor et al., 2015).

Oil spills

Oil spills from marine traffic could potentially affect multiple fisheries for significant periods of time. The anticipated increase in oil tanker traffic along the coast and over the dangerous Columbia River bar has led to stakeholder concerns about the risks of an oil spill to commercial, recreational, and tribal fisheries and how quickly they could recover from such an event (Industrial Economics Inc., 2014; Taylor et al., 2015).

Vessel safety

Fishery representatives have voiced concerns over the safety of fishermen operating in restricted spaces with high competition. This is of particular concern in the Dungeness Crab industry, where the first part of the season is marked with highly competitive, derby-style fishing. The pressure to catch as much crab as quickly as possible can lead to dangerous conditions. Individuals within the fishing industries have expressed great concern that further restrictions in fishing grounds will exacerbate safety issues and may increase fatality rates (Taylor et al., 2015).

Summary

In summary, there are many factors influencing the commercial and recreational fisheries of the Washington coast which lead to a significant level of uncertainty when forecasting future trends. What is certain, however, is the importance of this industry to the economy and social identity to coastal communities adjacent to the MSP Study Area and the state of Washington. Losses within these fishing sectors could mean a loss of jobs, income, and cultural way of life to coastal residents, including non-tribal and tribal residents. Fisheries stakeholders are concerned about further space restrictions from new ocean uses within the MSP Study Area and what this would mean for their industry (Industrial Economics Inc., 2014).

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2.5 Aquaculture

Aquaculture is a major use within the large coastal estuaries of the MSP Study Area. The shellfish aquaculture industry provides income and jobs to the region and the state, promotes environmental monitoring in the estuaries, and is a key part of the cultural history and identity in Pacific and Grays Harbor Counties.[1] As a state, Washington ranks first in shellfish aquaculture sales in the nation, with Pacific and Grays Harbor counties producing a substantial portion (about 29% in 2012) of the state's mollusk sales. The industry has a long history within the region and has adapted to several challenges to sustain a thriving industry. Current challenges such as invasive and nuisance species management, regulatory complexities, and climate change will continue to influence the future of aquaculture.

This chapter summarizes the history and current use of shellfish aquaculture in the MSP Study Area. Economic impacts, related infrastructure, and future trends of the industry are also presented here to outline the context of aquaculture and its role in the Washington coastal region.

Summary of History and Current Use

Marine aquaculture is one of the oldest industries in the state of Washington and includes a variety of shellfish species, marine plants, and net-pen-raised salmon. Washington is currently a leader in shellfish aquaculture production in the United States. The U.S. Census of Aquaculture from 2005 ranks Washington first in value of sales of farmed mollusks (over $63.7 million), with Washington-grown shellfish accounting for 31% of the value of U.S. farmed shellfish production (Industrial Economics Inc., 2014).

Aquaculture in the MSP Study Area is exclusively shellfish and occurs primarily in Willapa Bay (Pacific County), and to a lesser extent in Grays Harbor (Grays Harbor County). Nearly all of the shellfish farms are family-owned businesses, ranging from small "mom and pop" operations to larger, vertically-integrated farms with many thousands of acres. The communities of South Bend and Nahcotta on Willapa Bay are the primary centers for aquaculture activity (Industrial Economics Inc., 2014).

Native Olympia oysters (*Ostrea lurida*) originally dominated Willapa Bay and Grays Harbor. Heavy exploitation by the region's early Euro-American settlers resulted in the commercial extinction of Olympia oysters by the early 1900s, which lead to the development of oyster farms. Pacific oyster (*Crassostrea gigas*) spat was transplanted from Japan starting in 1928. Imports continued until the mid-1970s when Pacific oyster larvae began to be successfully reared in local hatcheries. A thriving oyster industry has existed in the region ever since. Pacific oysters have naturalized in Grays Harbor and Willapa Bay, yet hatchery production has been necessary to ensure stable aquaculture production and supply (Industrial Economics Inc., 2014). Beginning in the mid-2000s, hatcheries in the Pacific Northwest began to experience production failures. An increase in the acidity of coastal waters due to climate change is identified as the likely cause and hatcheries have had to adapt their practices to address the increased acidity in local coastal waters (Washington State Blue Ribbon Panel on Ocean Acidification, 2012).

Invasive and noxious species have also shaped estuary management and the shellfish industry. Most notably was the extensive infestation of the non-native cordgrass species *Spartina alterniflora* and *S. densiflora*. *S. alterniflora* was unintentionally introduced to Willapa Bay during the late 1800s. By 2003, it had spread to over 8,500 solid acres within Willapa Bay. *S. alterniflora* has been present in Grays

[1] Shellfish aquaculture is also important to the coastal tribes to sustain cultural and subsistence uses and provide commercial opportunities. Tribal shellfish aquaculture activities are not discussed in this chapter.

Harbor since the early 1990s and *S. densiflora* was discovered in Grays Harbor in 2001. Spartina is an aggressive plant that disrupts the ecosystem of the estuaries by outcompeting native vegetation and converting mudflats into Spartina meadows. This impacts shellfish beds, as well as migratory bird habitats (Washington State Department of Agriculture, 2015).

An extensive effort lead by the Washington State Department of Agriculture (WSDA) in partnership with Washington Department of Natural Resources (DNR), Washington Department of Fish and Wildlife (WDFW), Washington Department of Ecology (ECY), local governments, tribes, United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), and private landowners has resulted in the extremely successful reduction and control of Spartina. Control methods include herbicide applications and manual removal. In Pacific County (Willapa Bay) only 0.9 solid acres of *S. alterniflora* were reported in 2014, a 99.9% reduction since the peak in 2003. Dedicated resources, surveys, and removal treatments are ongoing to maintain the control program and prevent a resurgence of Spartina along the coast (Washington State Department of Agriculture, 2015).

Burrowing shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*) have also been a nuisance species to the aquaculture industry in Willapa Bay and Grays Harbor. These shrimp are native to Washington, but populations have grown drastically starting in the 1940s and 1950s. Burrowing shrimp destabilize the sediment and the beds become too soft to support oysters and aquaculture equipment which has a dramatic economic influence on the aquaculture industry. The pesticide carbaryl was used to control burrowing shrimp since the 1960s, yet was recently phased out of use. An integrated pest management plan has been in place for several years to develop cost effective and environmentally acceptable methods to control burrowing shrimp (Booth, 2007). [Note: Update on imidacloprid interest/permitting activity will be included in next draft of MSP.] Managing these species will continue to be a major challenge for the industry into the future (Taylor, Baker, Waters, Wegge, & Wellman, 2015; Washington State Department of Ecology, 2014).

The aquaculture industry is currently enjoying strong demand for its products; main products include oysters and manila clams. According to WDFW 2013 data, Pacific oysters account for about 82% of shellfish farmed and harvested in Pacific and Grays Harbor counties. Manila clams make up about 16% of harvest. Small amounts of eastern oysters, Kumomoto oysters, and blue and bay mussels are also produced (Figure 2.5-1). By value, Pacific oysters accounted for approximately 83% of the relative value for shellfish in Pacific and Grays Harbor counties, with Manila clams accounting for about 11% (Figure 2.5-2) (Industrial Economics Inc., 2014).

Pacific County produces more shellfish than Grays Harbor County. Harvest and value have varied over time (Table 2.5-1), and production data suggest that there has been a general decrease in Pacific oysters[2] and a general increase in Manila clams over the past 10 years (Industrial Economics Inc., 2014). Due to challenges in accurate and comprehensive reporting within the industry, WDFW recognizes that these numbers may under represent actual harvest. While WDFW data may not reflect true production values, they are currently the best available data to illustrate aquaculture production status and history (Industrial Economics Inc., 2014; Taylor et al., 2015).

[2] The reduction in oyster production is likely tied to the reduced number of oysters naturally reproducing in Willapa Bay. Most companies have traditionally relied on a combination of natural and hatchery produced oyster seed, and a reduction in natural oyster sets in Willapa Bay since the mid-2000s is now affecting the overall oyster seed supply (B. Sheldon, personal communication, May 26, 2016).

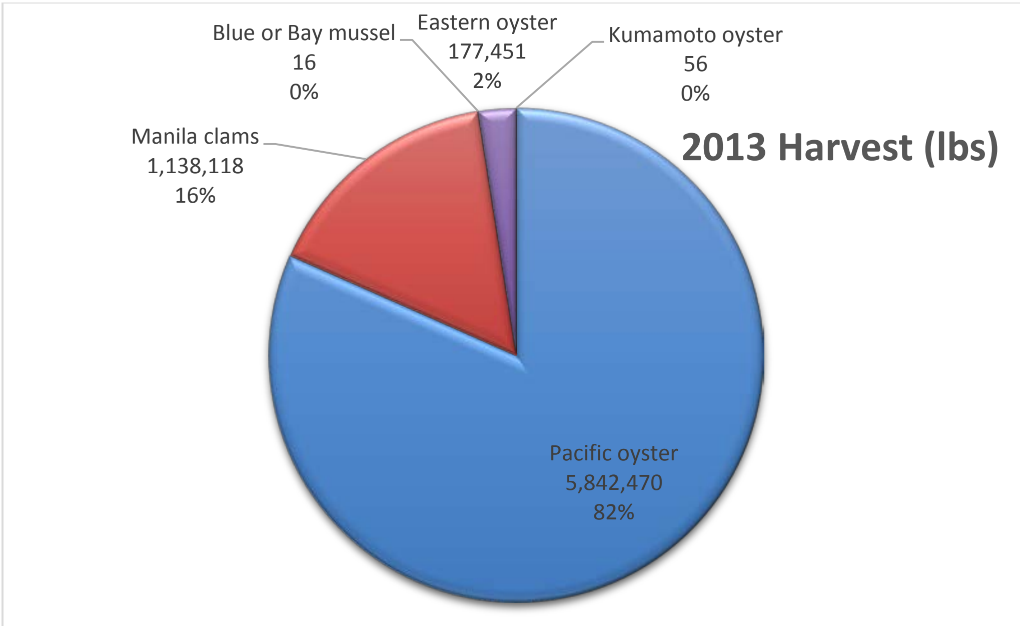

Figure 2.5-1. Relative harvest (round lbs) of farmed shellfish products in Pacific and Grays Harbor Counties, 2013. Source: Industrial Economics (2014).

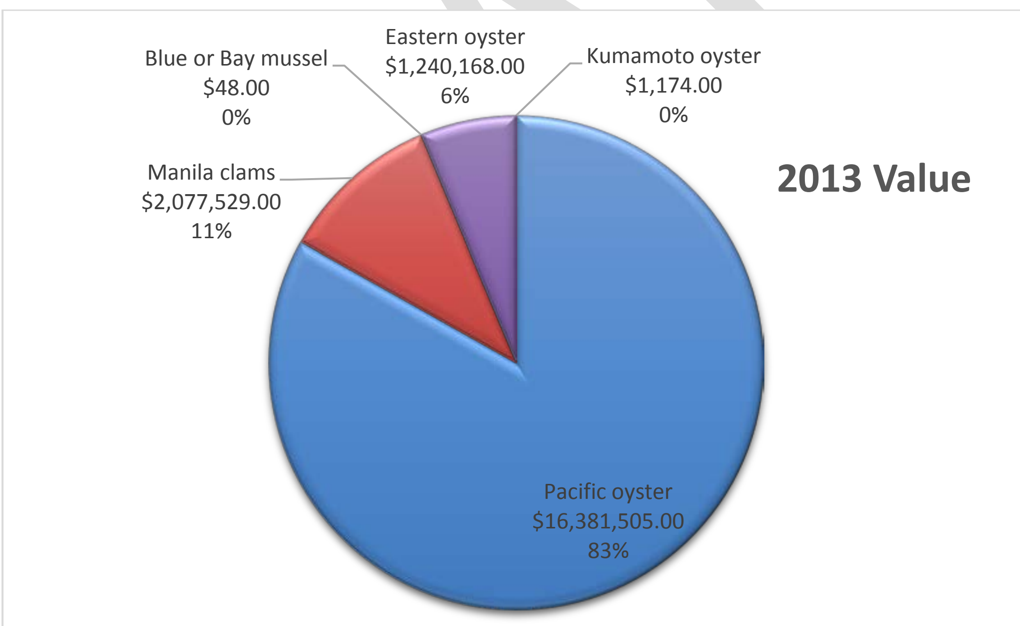

Figure 2.5-2. Relative value (dollars) of farmed shellfish products in Pacific and Grays Harbor Counties, 2013. Source: Industrial Economics (2014).

Table 2.5-1. High and low values for harvest (round lbs) and value (2014 $) of aquaculture Pacific oyster and Manila clams in Grays Harbor and Pacific Counties, 2004-2013. Source: Industrial Economics (2014).

Species	Gray Harbor County	Pacific County	Total

	Harvest (lbs)	Value	Harvest (lbs)	Value	Harvest (lbs)	Value
Pacific oyster	1,030,586-1,804,434	$3,519,614-$6,134,273	4,276,566-6,803,533	$11,194,059-$16,707,209	5,842,470-8,274,431	$16,381,505-$21,494,323
Manila clams	0-9,034	$0-$24,983	704,446-1,187,787	$1,419,160-$2,638,361	704,529-1,196,821	$1,419,160-$2,638,361

Willapa Bay and Grays Harbor make a considerable contribution to state-wide and national aquaculture production. According to the USDA, Pacific County ranked 3rd among all Washington counties and 15th among all U.S. counties in aquaculture sales with over $22.3 million in total sales in 2012. Grays Harbor ranked 7th statewide, and 43rd nationally, with $7.8 million in aquaculture sales. For mollusk production specifically, Pacific County and Grays Harbor County ranked 2nd and 4th, respectively, statewide in 2012. Pacific County produced about 23% of state farmed mollusk sales, and Grays Harbor County produced about 6% of statewide sales[3] (as cited in Industrial Economics Inc., 2014).

Reporting challenges make deriving consistent, representative participation numbers in the aquaculture sector difficult. The Willapa Grays Harbor Oyster Growers Association (WGHOGA) reports that in 2014, 28 growers were members in Willapa Bay and 7 growers were members in Grays Harbor. The number of farms can fluctuate on a regular basis, and are not always consistent with WDFW estimates (reported 20 farms in Willapa Bay and 6 farms in Grays Harbor in 2012) due to small operations or frequent changes that may not be reflected in WDFW reported numbers (Taylor et al., 2015). Another way to measure participation is through tideland leases. All reported shellfish farms operate on privately owned tidelands or on tidelands that are owned by the state and leased through DNR to growers. DNR reports that in 2015, approximately 50 leases were held for shellfish farming in Willapa Bay and Grays Harbor (DNR, personal communication, December 18, 2015). DOH also tracks the number of harvester and dealer licenses for commercial shellfish, as well as the number of certified harvest sites for the shellfish industry.

Shellfish aquaculture is an extensive spatial use of privately and publically owned tidelands in Willapa Bay and Grays Harbor. Commercially farmed acreage for aquaculture is estimated between 2,288 to 3,278 acres in Gray Harbor and 14,681 to 17,288 acres in Willapa Bay. This represents approximately 66% to 80% of the total acreage for shellfish aquaculture in the state[4]. There is significant uncertainty about the actual numbers of acres in aquaculture production because acreage is continuously rotated and some portions of tracts may go unused from year to year. Growers report that they typically farm between two-thirds and one-half of the acreage they own or lease (Taylor et al., 2015). In addition to privately owned and DNR leased lands, WDFW manages about 10,000 acres of intertidal and subtidal land as oyster reserves in Willapa Bay, and about 1,000 acres of these reserves are currently used for oyster production where licensed individuals may harvest naturally occurring oysters (WDFW, personal communication, May 23, 2016). Spatial use of the estuaries by the shellfish aquaculture industry is represented in Map 31.

Oyster production can be accomplished using natural (aka wild set) or artificial cultivation. In a natural set, naturally recruited oysters settle onto tidelands covered with oyster shells. Artificial cultivation requires the purchase or growth of oyster larvae, which are placed in upland tanks of

[3] County and growing area aquaculture production and sales amounts vary annually, and therefore so do relative rankings and percentages. Also, data discrepancies between WDFW, USDA, and industry sources may lead to varying results in sales and production numbers between reports.

[4] Estimates ranges are based on WDFW data compared with grower survey data.

warmed water that have been filled with bags of oyster shells onto which the larvae settle. After five to ten days, the shells with the settled larvae (aka “spat”) are removed and placed into a nursery area. They are then moved to a “grow-out ground” within the estuary, then transported again to a “fattening bed” where they mature and grow until they reach harvest size(Industrial Economics Inc., 2014). Oysters are primarily cultured using bottom culture methods, and some oysters are cultured using off-bottom techniques such as longlines, flip bags, and racks and bags. The vast majority (approximately 95%) of oysters cultured in Willapa Bay and Grays Harbor use bottom culture. 100% of Manila clam crops rely in bottom culture techniques. (B. Sheldon, personal communication, May 26, 2016).

Oysters are processed either by shucking or sold in-shell. Oysters for shucking are sent to shucking houses, where the meat is removed and packaged for sale. Shucked meat can also be used for smoked oysters. Oysters sold in-shell are generally purchased for cooking (e.g. on the grill) or to be eaten raw on the half shell (aka “shellstock”). Generally, larger oysters are sent to Asia, medium and small oysters stay in the U.S., and extra small oysters are sent to local oyster bars on the West coast. Demand for in-shell oysters is increasing, and some farms are expanding their in-shell production (Industrial Economics Inc., 2014). Clams are typically cleaned and bagged by the pound and sold to wholesalers or retail outlets. Some companies are vertically integrated; they farm, process, and distribute their product as well as provide a retail market. Other farms rely on separate processing facilities and distributors to move their product (Taylor et al., 2015).

The aquaculture sector makes significant contributions to social, cultural, and environmental systems. Ecologically, oyster beds are important biogenic habitat. They form complex structures that provide refuge and hard substrate for marine plants and animals, enhancing biodiversity. Shellfish in the estuaries provide important nursery habitat for commercially and recreationally important species, such as fish, crab, and others. Research also suggests that shellfish provide environmental services, such as water quality improvement through nitrogen removal (Skewgar & Pearson, 2011; Taylor et al., 2015).

Shellfish aquaculture can also bring water quality impairments to the attention of local communities. Because of stringent U.S. health standards for water in which shellfish fisheries and aquaculture operate that are set by the National Shellfish Sanitation Program, these coastal areas often have amplified monitoring of environmental conditions. Harvest area closures due to water quality impairments can result in economic hardships for the industry (Taylor et al., 2015). The industry has assisted state and local government agencies, tribes, and private citizens in the planning and implementation of improvements to sewage treatment systems or programs to fix local septic systems, and other water quality pollution reduction programs. The aquaculture industry is often a protective steward of water quality in and along the coastal estuaries.

The aquaculture industry is managed through a complex interaction of multiple agencies, each with its own mandate, jurisdiction, and standards related to aquaculture. Table 2.5-2 provides a summary of the primary agencies involved with shellfish aquaculture and their general role.

Table 2.5-2-. Primary regulatory agencies for Washington shellfish aquaculture and their roles.

Agency	Role
Washington Department of Ecology	Ensures Coastal Zone Management Act consistency Ensures Shoreline Management Act consistency through review and approval of certain Shoreline Permits

	Issues 401 Water Quality Certifications for new and expanded aquaculture operations Issues NPDES permits for herbicide and pesticide applications
Washington Department of Natural Resources	Leases state-owned aquatic lands and authorizes use of those lands for aquaculture operations
Washington Department of Fish and Wildlife	Manages oyster reserves, processes aquatic farm registrations, and authorizes in-state and out-of-state shellfish importation and transfer
Washington Department of Health	State Shellfish Authority, ensure compliance with the National Shellfish Sanitation Program Sets growing area classifications and boundaries; monitors water quality for toxins, pathogens, and viruses; closes areas that are unsafe for harvest; licenses and inspects commercial shellfish harvest and operations; certifies harvest sites; and responds to shellfish related reports and outbreaks
United States Army Corps of Engineers	Requires a Section 404 permit for the discharge of material into waters of the United States Requires a Section 10 permit for work in navigable waters of the United States
Washington Department of Agriculture	Safeguards the public from consuming unsafe, adulterated, or misbranded food through processing plant licenses and product identification requirements Oversees the control of noxious and invasive species Issues registrations for pesticides
Local Governments	Issues aquaculture use permits under local Shoreline Master Programs to protect natural resources, provide for public access, and plan for water-dependent uses

Economic Impact of Aquaculture

The coastal shellfish aquaculture industry provides a significant contribution to the local and statewide economy. However, comprehensive economic impact estimates are particularly challenging to generate for this industry due to discrepancies between state collected data and other reports from the industry. Taylor et al. (2015) analyzed data from the state, supplemented with surveys from the shellfish harvesting and processing industry, to estimate the economic contributions of the industry for the MSP.[5] Economic contributions include direct expenditures by the industry, as well as indirect and induced effects generated by those industry expenditures, including the total number of jobs and total labor income. Expenditures, total employment, and total labor income generated by the shellfish aquaculture industry in Pacific and Grays Harbor Counties are presented in Table 2.5-3.

Expenditures made by the shellfish industry include payments for goods and services such as payroll and benefits, seed oysters, ice, packaging, and taxes. A survey of processors and distributors indicate that about 71% of expenditures made by survey participants are made locally in Washington's coastal counties, with 94% of expenditures made within Washington State. About 847 jobs and $50 million in labor income are generated by the aquaculture industry (growing and processing) in the Washington coastal region. An additional 383 jobs and $23.2 million in total labor income are generated in Washington State outside of the coastal region by the coastal aquaculture sector's activities (Table 2.5-3) (Taylor et al., 2015).

Table 2.5-3. Estimated regional expenditures by the Pacific coast shellfish aquaculture industry and total economic contribution (employment and labor income) to the Washington coast region and statewide. Source: Taylor et al. (2015).

	Expenditures	Total Employment	Total Labor Income
Washington coast region	$65.2 million	847	$50 million
Statewide	$78 million	1,230	$73.2 million

Included in the total economic contribution to the state economy from shellfish aquaculture are revenue to the state from aquaculture land leases, license, and permit fees paid by shellfish farmers, and sales for access to the state-owned Willapa Bay Oyster Reserves for commercial harvest[6] (Taylor et al., 2015). DNR leased lands generated about $327,230 in revenue in 2010, and oyster sales from the Oyster Reserves have averaged about $173,000 per year with clam sales averaging about $15,000 per year (Industrial Economics Inc., 2014).

At the county level, Pacific County in particular has a high economic dependence upon shellfish aquaculture. A report by Washington Sea Grant (2015) estimated that in 2010, 20% of Pacific County's total economy relied on aquaculture. This indicates that Pacific County's economy is at relatively high risk if the industry reduces business activities or closes down.

Industry representatives, state managers, and economists understand well the limitations of the above aquaculture economic contribution estimates. The Washington State Shellfish Initiative is looking to address this issue by designing a system to improve data collection and sharing of information on the economics of shellfish (Office of the Governor, 2016).

Related Infrastructure

[5] The estimates produced by the Cascade Economic study (Taylor et al. 2015) are based on information from 2013. The multipliers used were derived using the IMPLAN models based on 2012 regional economic data.

[6] 60% of the proceeds from the sales of oysters on the reserves goes to research activities in Willapa Bay (WDFW, personal communication, May 31, 2016).

Hatcheries

Shellfish hatcheries are vital to the aquaculture industry. Four companies provide hatchery larvae to farms in Willapa Bay and Grays Harbor: Whiskey Creek Shellfish Hatchery of Netarts, Oregon, Taylor Shellfish of Shelton, Washington, Coast Seafoods Company of Bellevue, Washington (now owned by Pacific Seafood), and the Nisbet Oyster Company of Bay Center, Washington. Some other companies are able to produce some larvae for their own operations, but it is often not enough to fulfill their entire seed need. Most hatchery production occurs in the Pacific Northwest, however the Nisbet Oyster Company has an operation in Hilo, Hawaii, Coast Seafoods has a clam larvae operation in Kona, Hawaii, and Taylor Shellfish has nurseries in California and Hawaii. Some operations in Hawaii were in response to the large scale oyster larvae failures in the mid 2000's and the concern of ocean acidification (Industrial Economics Inc., 2014; Taylor et al., 2015).

Processors

Processing facilities are also vital to the sale of shellfish aquaculture product. Processing can consist of simply cleaning the shell to prepare for selling live[7], or the product can be processed in-shell (non-living) or be shucked and packed. The DOH has different licensing requirements for different categories of shellfish processors (aka "dealers"). Processors can be licensed to perform various processing and selling activities (e.g. shellstock shippers vs. shucker-packers, etc. [8]). Several processing companies that are licensed to shuck shellfish operate in Pacific County, including Coast Seafoods, Nisbet Oyster Company, Wiegardt Brothers, Ekone Oyster Company, Bay Center Mariculture, Chetlo Harbor Shellfish, Palix Oyster Company, and South Bend Products. Another large company, Taylor Shellfish, ships its product out of the Study Area to a facility in Shelton for processing. Processing in Grays Harbor is more limited, with Brady's Oysters and Lytle Seafood being the only processers of oysters in the area (Industrial Economics Inc., 2014; L. Johnson (DOH), personal communication, December 22, 2015).

Processors also ship their product in- and out-of-state, as well as overseas. Many processing companies transport the product themselves or rely on another company or consolidated shipper (Taylor et al., 2015; L. Johnson (DOH), personal communication, December 22, 2015).

Water access

As an estuary use, water access is required for the farming of shellfish. Willapa Bay has marinas that are primarily used by oyster growers, such as Bay Center Marina and Nahcotta, to transport and store boats, along with other aquaculture water access related activities. Some farms and processors have their own private docks and water access for operations in Willapa Bay and Grays Harbor.

Future Trends

Shellfish growers and processors face many current challenges and future uncertainties within the industry. Primary among future uncertainties are invasive and native nuisance species control, regulatory and policy changes, climate change, workforce availability, and changes to estuary uses. Experimentation with geoduck culture and the development of the Manila clam market are opportunities for aquaculture expansion.

Invasive and native nuisance species control

[7] DOH uses the term "shellstock" to describe oysters that are washed and kept live.

[8] For descriptions of the various dealer license categories, please see Industrial Economics (2014).

Invasive and native noxious and nuisance species are perceived by aquaculture stakeholder representatives as the greatest threat to the industry (Industrial Economics Inc., 2014). While the 99.9% reduction of Spartina in Willapa Bay is a substantial success story (Washington State Department of Agriculture, 2015), other invasive and nuisance species pose current and future risks to aquaculture growing conditions in Willapa Bay and Grays Harbor. Current species include (but are not limited to) the noxious weed[9] Japanese eelgrass (*Zostera japonica*), burrowing shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*), and two species of non-native oyster drills (*Ceratostoma inornatum* and *Urosalpinx cinerea*) (Industrial Economics Inc., 2014; Taylor et al., 2015).

The impacts on aquaculture production by nuisance species can be quite significant, with one expert suggesting declines of as much as 10%-20% in shellfish production per year in areas of high burrowing shrimp populations. Controlling burrowing shrimp can be quite challenging and costly to the industry, and currently requires the use of pesticides to be effective. Similarly, Japanese eelgrass also requires the use of herbicides for control. The industry must comply with several regulations to treat oyster beds with pesticides, including obtaining permits from ECY, and following the label requirements on pesticide registrations from the WSDA and the U.S. Environmental Protection Agency (EPA). Even so, the application of chemicals for these species in some cases is environmentally controversial and has been met with resistance from certain consumer and public groups, adding to the challenge the aquaculture industry faces in managing nuisance species.

In addition, new species may be introduced in the future or environmental changes to the estuaries could result in a species interaction shift that can have unforeseen impacts to aquaculture. Present day and potential future invasive and nuisance species will continue to be a threat and create significant operational, regulatory, and economic challenges for the aquaculture industry (Industrial Economics Inc., 2014; Taylor et al., 2015).

Regulatory burden and uncertainty

Regulatory requirements are seen by many industry representatives as complicated, burdensome, costly, time consuming, and not conducive to a growing aquaculture industry. Main concerns voiced include: (1) resources required to comply and keep up with permit application, renewal, and reporting requirements, etc.; (2) as a result of new permit requirements, the industry is vulnerable to additional challenges or appeals which can result in expensive legal proceedings; and (3) environmental requirements with which shellfish farms must comply are burdensome. The complicated nature of aquaculture industry regulations is a current challenge, and will continue to pose challenges to the future of the industry, particularly if new, more restrictive regulations are put into place (Industrial Economics Inc., 2014; Taylor et al., 2015). The Shellfish Interagency Permitting Team, part of the Washington Shellfish Initiative, has recently released recommendations to address permitting challenges in the aquaculture industry and will continue to work to improve the permitting process (Lund & Hoberecht, 2016).

Climate Change

A changing climate could lead to alterations of environmental conditions within the estuaries, and ultimately the growing conditions for the aquaculture industry. Among the key concerns related to climate change are the consequences of ocean acidification, sea level rise, and water temperature.

[9] A "noxious" weed in Washington is the traditional, legal term for any invasive, non-native plant that threatens agricultural crops, local ecosystems or fish and wildlife habitat. For more information on noxious weeds in Washington, including Japanese eelgrass, go to http://www.nwcb.wa.gov/default.asp

Ocean acidification is one of the primary environmental concerns for the shellfish aquaculture industry in the MSP Study Area as well as elsewhere in Washington. As ocean acidity increases, calcium carbonate upon which young oysters rely to grow their shells becomes less available. This leads to thinner shells, slower growth rates, and higher mortality rates. Because oysters and other shellfish are most vulnerable when they are young, scientists believe that ocean acidification is likely the cause of failure of the natural set in recent years, as well as large scale hatchery failures using local seawater. The state of Washington has recognized the severity of this issue and potential risks to the economy and culture of the aquaculture industry, and the Governor's office has taken a number of steps to promote research and actions to address this issue, including a Washington State Blue Ribbon Panel on Ocean Acidification (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Based on the Blue Ribbon Panel recommendations the Governor and legislature created the Marine Resource Advisory Council and the Washington Ocean Acidification Center to advance coordinated efforts to address ocean acidification.[10]

Hatcheries and oyster production companies have incurred considerable costs to address the consequences of ocean acidification, and are investing for the future in anticipation of further increases in ocean acidity. The Blue Ribbon Panel estimated that ocean acidification has already cost the oyster industry over $110 million. One company has opened a hatchery in Hawaii to avoid the increased acidification of waters entering the Pacific Northwest, which has increased the cost of producing and providing oyster spat. Many companies may not have the means to relocate hatcheries if they own one or may not be able to absorb the costs of purchased spat (Industrial Economics Inc., 2014; Taylor et al., 2015).

The failure of natural oyster sets (either from ocean acidification or other conditions) creates challenges and increased costs for the oyster industry. One company has seen a five to six time increase in seeding process costs. The failure of a natural set in the Willapa Harbor State Oyster Reserve, which depends completely on the occurrence of natural larvae sets, will diminish oyster supply. This in turn will decrease income provided by the reserve as well as reduce the quality of oyster habitat and the associated ecosystem services within Willapa Bay (Industrial Economics Inc., 2014; Taylor et al., 2015).

Sea level rise may also impact the shellfish industry. Most shellfish culture occurs on the intertidal substrate, and the intertidal zone will shift landward or be reduced as a result of sea level rise. This may decrease access to aquaculture beds, decrease available harvest time at low tides, and likely shift optimal growing areas. Changes in property boundaries and harvest areas will create logistical and management challenges for the oyster industry (Taylor et al., 2015).

As water temperatures rise with climate change, the shellfish industry could be impacted in a number of ways. First, increased temperatures may reduce shellfish growth, reproduction, distribution, and health. Second, rising water temperatures may increase the occurrence of Harmful Algal Blooms (HABs), which can produce natural toxins that cause human illness or death when they are concentrated within filter feeding shellfish, and bacteria, which also can cause human illness. *Vibrio parahaemolyticus* is a naturally-occurring bacterium common in Washington in the warm summer months. *V. parahaemolyticus* causes illnesses each year, mostly impacting consumers of raw oysters. DOH is responsible for monitoring HABS and *V. parahaemolyticus* in shellfish growing areas. DOH is concerned that HABs and *V. parahaemolyticus* will increase in frequency, duration, and severity with rising water temperatures. Rising water temperatures may also result in new, more dangerous varieties of toxins and other pathogens. DOH tracks reports of shellfish-related illnesses and monitors for emerging toxins and

[10] More information on the Marine Resource Advisory Council can be found at http://www.ecy.wa.gov/water/marine/oceanacidification.html

pathogens in close collaboration with research partners at the National Oceanographic and Atmospheric Administration (NOAA), the Food and Drug Administration (FDA), and academia. The emergence of new toxins and pathogens would result in a significant negative economic impact to the industry (Industrial Economics Inc., 2014; Taylor et al., 2015; L. Johnson, personal communication, December 22, 2015).

Potential changes to estuary uses

Changes in the intensity and frequency of current co-uses of the estuaries may influence the shellfish aquaculture industry on the coast. Projected increases in crude oil transportation by ship and by rail is of particular concern (See Section 2.7 Marine Transportation, Navigation, and Infrastructure). Concerns center on the risk of an oil spill, and the potential severe impact it could have to the industry through contamination of shellfish beds. Another concern for Grays Harbor growers is the federal navigation channel deepening (See Section 2.10.3 Dredge Disposal). Past navigational dredging is believed to contribute to loss of oyster beds now buried by sand, decreased production from wave action, and changes in substrate size (Industrial Economics Inc., 2014). These changes to marine traffic and increases in oil transportation place additional uncertainty for the future of the aquaculture industry.

Potential new uses addressed within the Marine Spatial Plan also cause some concern among industry representatives. Aquaculture is highly dependent upon environmental conditions such as water flow and water quality. Some representatives are concerned about what effect a Marine Renewable Energy project within or near the estuaries may have on water flow (Industrial Economics Inc., 2014). Another potential concern is the possibility of net pen aquaculture within the estuaries. Finfish aquaculture can be associated with reduced water quality in shallow and poorly flushed sites (See Section 2.10.2 Offshore Aquaculture). There is currently no net pen aquaculture (finfish) within the estuaries. If net pens were to be developed within Grays Harbor or Willapa Bay, growers may be concerned about potential water quality changes and the consequences for the shellfish industry. Currently, there is no known active interest in net pen aquaculture in Willapa Bay or Grays Harbor and it is unlikely this activity would be sited here in the future.

In summary, even while facing several existing challenges and future uncertainties, the aquaculture industry is currently enjoying strong demand for its products. Experts believe the industry can continue to grow and thrive if: the industry is able to innovate and adjust to changing climatic conditions and other challenges, such as invasive and nuisance species; policy makers can address concerns of uses such as crude oil transportation; and the regulatory structure allows for a reasonable and flexible opportunity to address these challenges. Furthermore, experts have identified areas of potential expansion into the culture of geoduck clams and further develop production and markets for Manila clams (Industrial Economics Inc., 2014). Aquaculture is important economically and socially to the coast and the state of Washington, and will continue to play a role in future policies and decisions for coastal and marine uses.

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2.6 Recreation and Tourism

The Pacific Coast of Washington relies on an economy based in recreation, tourism, and natural resources. The tourism and recreation benefits offered by the mostly rural coast are important to both the residents of local communities and also to visitors from throughout the state and beyond. A survey by Point 97 and the Surfrider Foundation (2015) found that recreational visits to the coast by Washington residents are a substantial driver for local economies with spending of $481.2 million in the 2014.

This chapter summarizes the role of recreation and tourism in the MSP Study Area and highlights popular recreational activities. The economic impacts, related infrastructure, and future trends of recreation and tourism are also described here.[1]

Summary of History and Current Use

The natural setting of Washington's Pacific coast has always been a major draw for visitors and residents. Large portions of the Washington coast have been designated to protect and facilitate public recreation. For example, Olympic National Park was established in 1938 by President Roosevelt and has three park districts directly on the coast adjacent to the Study Area (Industrial Economics Inc., 2014). Another example is the Washington State Seashore Conservation Act of 1967 which recognized the importance of the pristine Washington shoreline in "…provid(ing) the public with almost unlimited opportunities for recreational activities, like swimming, surfing, and hiking; for outdoor sports, like hunting, fishing, clamming, and boating; for the observation of nature as it existed of hundreds of years before the arrival of Europeans; and for relaxation away from the pressures and tensions of modern life" (RCW 79A.05.600) and established much of the southern area of the coast as a Seashore Conservation Area for public recreation use and enjoyment.

The northern portion of the MSP Study Area (Clallam and Jefferson Counties) is a rugged, dramatic cliff coastline with limited public access points. The Makah, Quileute, and Hoh Indian Tribes have reservation lands in the northern portion, and much of the rest of the northern coast is within the Olympic National Park. Recreational features of the northern coast include Cape Flattery; Olympic National Park's campgrounds and trails; several surfing beaches; coastal trails and beaches for walking, hiking, and camping; and various tribal facilities, including lodging, marinas, and trails. The northern coast primarily attracts visitors looking to spend time connecting with nature (Industrial Economics Inc., 2014).

The southern coast (Grays Harbor and Pacific counties) provides visitors with opportunities to enjoy nature while taking advantage of amenities associated with more developed areas. The southern coast is dominated by long, sandy beaches as well as the two large estuaries with calmer waters protected from the open ocean. The southern coastal area contains more than ten state park facilities, the Seashore Conservation Area (SCA), the Quinault and Shoalwater Bay Indian Reservations, and several major coastal communities (Maps 1 and 2). Second-home communities that incorporate amenities and rental programs have become popular along the southern coast (Industrial Economics Inc., 2014).

Recreation Activities

[1] Recreational fishing is not included in this section as it is covered in Section 2.4 Commercial, Recreational, and Tribal Fisheries.

A panel survey conducted in 2014-2015 by Point 97 and the Surfrider Foundation (2015) collected data on Washington resident recreation activities in the MSP Study Area. The survey evaluated where respondents recreated, what types of activities they participated in, and how much they spent on various activities and trips.[2] In total, the study estimated that Washington State residents (18 years of age and older) take about 4.1 million trips to the MSP Study Area per year. Pacific (37%) and Grays Harbor (35.6%) counties received the largest proportion of recreational trips to the Study Area by WA residents, followed by Clallam (20.2%) and Jefferson (7.2%) counties. Areas with high densities of recreation trips include Ocean Shores, Westport, Long Beach/Seaview, Pacific Beach, La Push, and Kalaloch, although it is clear that the entire MSP Study Area coast has some usage for recreation (Map 32) (Point 97 & Surfrider Foundation, 2015).

Respondents were asked to identify all of the recreational activities they participated in during coastal trips to the MSP Study Area in the previous twelve months. The top five most popular activities identified were beach going (67.7%), sightseeing/scenic enjoyment (62.3%), watching marine life from shore (39.9%), photography (36.3%), and hiking or biking (33.1%). Respondents were also asked to identify their primary activity on their most recent trip and the top three primary recreation activities in the MSP Study Area were beach going (32%), sightseeing/scenic enjoyment (22.6%), and camping (11.3%). Other types of recreational activities along the coast include swimming, beach driving, tide pooling, surfing, kayaking and paddle boarding, SCUBA diving, windsurfing, boating, horseback riding, whale watching, and others (Point 97 & Surfrider Foundation, 2015). Maps displaying the spatial intensity of grouped and individual recreational activities in the MSP Study Area can be found in the Point 97 & Surfrider Foundation (2015) report. Some of the recreational activities are highlighted below.

Wildlife viewing

Wildlife viewing from shore ranked highly as a frequent activity among coastal visitors to the MSP Study Area. Visitors also participate in wildlife viewing on the water from private boats and charter boats or guide services. Popular marine wildlife to view along the coast, in the estuaries, and on the ocean include a variety of birds like bald eagles, osprey, blue herons, brown pelicans, and snowy plovers; and marine mammals like whales, seals, otters, and sea lions. The peak season for whale watching is between March and May as gray whales migrate along the coast, and even can be found swimming inside Grays Harbor. Humpback whales can also be spotted as they migrate seasonally along the coast (City of Hoquiam & Washington State Department of Ecology, 2016). Along the Northern coast, Neah Bay offers opportunities to view seabirds, sea lions, and Gray whales. La Push offers whale watching from the beach and boat charters out of the marina to view the Gray whale migration near shore and occasionally transient orcas. South of La Push through Kalaloch and Queets are many more opportunities to view wildlife including whales, brown pelicans, sea lions, harbor porpoise harbor seals, and sea otters. On the Southern Washington Coast the whale watching and wildlife viewing opportunities continue near Moclips, Pacific Beach, Copalis, and Ocean City. In Westport, whale watching tours are available leaving from Westport Marina. In the Ocean Shores area, Damon Point and the Oyehut Wildlife Recreation Area are notable for their bird watching opportunities (Taylor, Baker, Waters, Wegge, & Wellman, 2015).

The Grays Harbor and Willapa Bay estuaries and wildlife refuges are particularly popular sites for shore-based bird watching. The Grays Harbor National Wildlife Refuge (NWR) is a migration stopover for thousands of shorebirds in the spring and fall (Taylor et al., 2015). The peak bird migration is typically in late April and early May. Thousands of people attend the Grays Harbor Shorebird Festival to

[2] Details on the methodology used are available in the full report: Point 97 & Surfrider Foundation, 2015.

view the migration of hundreds of thousands of Arctic-bound shorebirds. The festival features shorebird viewing, field trips, lectures, and a birding market place and nature fair (City of Hoquiam & Washington State Department of Ecology, 2016). The Willapa National Wildlife Refuge (NWR) estimates that in 2010 there were 109,500 visitor use days to participate in wildlife observation/photography. The diverse habitats found at Willapa NWR support over 200 species of resident and migratory birds. At Leadbetter Point on the northern tip of the Long Beach Peninsula over 100,000 birds can be seen during the peak spring migration (U.S. Fish and Wildlife Service, 2011).

Waterfowl hunting

Waterfowl hunting is another recreational use of the areas adjacent to the MSP Study Area. The Washington Department of Fish and Wildlife (WDFW) has management authority for all non-tribal waterfowl hunting within the state, and all hunting requires a small game license and potentially additional regulations depending on the species. Treaty tribes set hunting regulations for their members and tribal members do not require a state license (Skewgar & Pearson, 2011).

Duck and goose hunting occurs in all of the coastal counties. Statistics from WDFW for 2015 show the numbers of duck and goose hunters are highest in Grays Harbor County while the rate of harvest is highest in Pacific County for both ducks and geese. See Table 2.6-1 and Table 2.6-2. The Willapa NWR estimates that in 2010 there were 350 visitor use days to the refuge to hunt waterfowl (U.S. Fish and Wildlife Service, 2011), while the Grays Harbor NWR does not allow hunting.

Table 2.6-1: 2015 Recreational duck hunting in WA coastal counties. Source: WDFW

County	Number of Hunters	Hunt Days	Harvest	Harvest Rate (harvest/days)
Clallam	379	2231	5815	2.61
Jefferson	210	1228	2278	1.86
Grays Harbor	865	4765	11144	2.34
Pacific	398	2080	5866	2.82

Table 2.6-2: Recreational goose hunting in WA coastal counties. Source: WDFW

County	Number of Hunters	Hunt Days	Harvest	Harvest Rate (harvest/days)
Clallam	118	836	331	0.40
Jefferson	31	207	24	0.12
Grays Harbor	224	839	542	0.65
Pacific	123	626	827	1.32

Clamming

A particularly popular recreational activity on the south Washington Pacific coast is razor clamming. Razor clam (*Silqua patula*) recreational harvesting, cleaning, cooking, eating, and canning have been an important focus of family relationships and local culture in Washington State coastal communities for many generations. With between 275,000 and 460,000 seasonal digger trips harvesting as many as 6.1 million clams, the fishery generates between $25 and $40 million in tourist related income per season to the economies of small coastal communities (Ayres, D., WDFW, personal communication, June 1, 2016). Clamming is allowed at designated beaches along much of the southern half of the Washington coast Map 29. Occasional long-term area closures of the razor clam fishery due to increases in levels of naturally occurring marine biotoxins (caused by harmful algae blooms) can significantly disrupt the fishery, as well as negatively impact the coastal tourism industry which significantly benefits from recreational razor clammers visiting the coast (Ayres, D., WDFW, personal communication, June 1, 2016). For more information on the recreational razor clam fishery, please see the Fisheries chapter.

While razor clamming is a more popular recreational activity, there is also a recreational hardshell clam fishery. Hardshell clams includes littleneck clam (*Leukoma staminea*) and butter clam (*Saxidomus gigantea*). The National Park Service has done some population assessment of hardshell clams on beaches in Olympic National Park (Map 29). Hardshell clamming differs from razor clamming in that there is a relatively lower density of hardshell clams; they live on remote, exposed, wilderness beaches; and digging them is more challenging because they live in a mixed-coarse substrate of sand, gravel, and cobble. The hardshell clam recreational fishery in Olympic National Park is relatively small due to the challenges of harvest and lower density (Fradkin. S., NPS, personal communication, October 28, 2016). WDFW does allow harvest of hardshell clams within the Willapa Bay estuary and those stocks receive greater harvest pressure (Ayres, D., WDFW, personal communication, November 18, 2016).

Boating

As seen in Map 33, recreational vessels transit the majority of the MSP Study Area. Recreational vessels, as defined for the study, include private vessels like sailboats, motorboats, and small independent fishing boats only when they are transiting the area but not when fishing. The data for the map was obtained through the Automatic Identification System (AIS) which is a tracking system used on ships and by vessel traffic services for identifying and locating vessels by electronically exchanging data.[3] Recreational boaters on the Pacific Coast of Washington participate in a variety of activities including sailing, cruising, viewing wildlife, and fishing. One unique activity on the coast is the Coho Ho Ho, a sailing rally from Puget Sound to San Francisco. About a dozen boats participate annually, and while the organization does not recommend specific routes to each boat, they suggest a halfway stop in Newport, OR and educate participants to be responsible boaters. Many of the participants will continue from San Francisco down to San Diego to join up with the larger Baja Ha Ha sailing rally with a final destination of Cabo San Lucas, Mexico. (Lombard, D., Coho Ho Ho, personal communication, October 26, 2016).

Surfing

Surfing is practiced by a relatively small percentage of the overall recreational user community, yet surfers are a dedicated user group. Surfers are known to make frequent trips to the coast and, therefore, are considered avid users of coastal resources and important contributors to local economies. Surfers travel great distances to reach quality waves. While surfers are predominately from Washington,

[3] While AIS is required for larger vessels, it is not required for recreational private vessels. Therefore, some recreational vessels are not represented in this map. The map only includes data from vessels that choose to use AIS.

visitors from Oregon and British Columbia are common at Washington surf spots. Surfers also come from as far away as Montana, California, the East Coast, and even Australia. Several surfing spots are scattered along the Washington coast. The Clean Water Classic, the longest running Pro/Am Surf Competition in the Pacific Northwest, is held in Westport in early October. The event is organized by volunteers and draws nearly 700 visitors, benefiting the Surfrider Foundation chapters in Washington, Oregon, and British Columbia (Dennehy, C., Surfrider, personal communication, August 10, 2016).

Beach prospecting

Ocean beach prospecting is another recreational use with a relatively small, yet committed group of people that participate. Beach prospecting first began on Washington's coastal beaches in 2008, when interest from the prospecting community prompted a two year pilot program for beach prospecting on three beaches within the SCA jointly evaluated by WDFW and Parks (Washington Department of Fish and Wildlife & Washington State Parks and Recreation Commission, 2010). The pilot program was successful, and currently, small scale mining and prospecting are allowed year round on ocean beaches within the SCA between the line of ordinary high tide and the line of extreme low tide. This activity is managed by WDFW and Parks, and miners are required to follow the rules within the WDFW Gold and Fish pamphlet (a type of umbrella Hydraulic Project Approval) (Washington Department of Fish and Wildlife, 2015). Because WDFW no longer issues individual Hydraulic Project Approvals (HPA) for this activity and Parks does not quantitatively track ocean prospecting, the State cannot provide current participation numbers. The most recent estimates are during May 2014 – July 2015, when WDFW required individual HPAs for beach prospecting, and issued about 260 HPAs for this activity (Aaron, K., WDFW, personal communication, June 1, 2016).

Economic Impact of Recreation and Tourism

Recreation has always been a part of the economy in the coastal counties. Historically, recreation and tourism have played a small part relative to other industries such as fishing, forestry, and manufacturing, yet the recreation and tourism sector is growing and increasing in prominence (Taylor et al., 2015). Currently, recreation and tourism are often the most popular human uses of coastal and marine settings. A 2011 study on the ocean economy for the five Pacific coast counties (Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum) adjacent to the MSP Study Area shows that tourism and recreation was the largest sector and accounted for approximately 78 percent of employment and 50 percent of GDP for the portion of the economy that depends directly on ocean resources. This study was not limited to the Study Area, but also includes Wahkiakum County, and the portions of Clallam and Jefferson counties adjacent to the Strait of Juan de Fuca and Puget Sound (NOAA Coastal Services Center, 2014).

Specific to the MSP Study Area, survey respondents spent an average of $117.14 per person per coastal trip in 2014-2015, and Point 97 & the Surfrider Foundation (2015) estimated that the total annual coastal trip spending by Washington residents was about $481.2 million statewide (Table 2.6-3). This and other surveys indicate that Washington residents and out-of-state visitors spend the most money on accommodations, food and beverages, and transportation when visiting the coast (Point 97 & Surfrider Foundation, 2015; Taylor et al., 2015). Estimated trip spending associated with MSP Study Area coast trips by out-of-state visitors is about $160 million within the coastal region, with an additional $29.8 million spent elsewhere in the state (Table 2.6-3) (Taylor et al., 2015).

Recreation and tourism trip spending in the MSP Study Area generates economic activity that supports jobs and personal income for residents of the coastal area and elsewhere in the state. In the coastal study area, recreation trip-related spending by Washington residents is estimated by Taylor et al.

(2015) to support 4,725 jobs and $196.8 million in labor income within the coastal economy. As dollars and economic activity multiply through the state's economy, an estimated 9,309 jobs statewide are supported directly and indirectly by recreation and tourism in the coastal area, as well as $413 million in labor income (Table 2.6-3).[4] Many communities along the MSP Study Area are heavily reliant on employment generated by the recreation and tourism industry. For example, resident employment in tourism-sensitive industries exceeds 50% of overall employment for communities such as Pacific Beach (57.5%), Copalis Beach (82%), Ocean City (85.7%), and Seaview (57.5%) (Taylor et al., 2015).

Table 2.6-3. Estimated recreation and tourism trip spending associated with Study Area coastal trips by Washington State residents and out-of-state visitors and total economic contribution (employment and labor income) to the Washington coast region and statewide. Source: Taylor et al. (2015).

	Trip spending by WA residents	**Trip spending by out-of-state visitors**	**Total employment** (from trip spending by WA residents)	**Total labor income** (from trip spending by WA residents)
Washington coast region	$330.9 million	$160 million	4,725	$196.8 million
Statewide (total)	$481.2 million	$189.8 million	9,309	$413 million

Related Infrastructure

Coastal recreation and tourism activities are linked closely with available access for outdoor activities and supporting amenities such as lodging or camping, food, and entertainment. As noted earlier, the northern and southern coastal regions differ in the types of recreational and tourism experiences they offer, as well as supporting public access and amenities. The northern coastal region offers recreation and tourism users with an opportunity to connect with nature in a more private and rugged wilderness setting supported by Olympic National Park lands, coastal hiking, surfing, and a few camping and lodging amenities. The southern coast provides users with long sandy beaches optimal for kite flying, beach driving, razor clamming, horseback riding, and other activities. Several coastal communities are nearby to support dining and lodging options.

National Park and Wildlife Refuges

Olympic National Park is located on the Olympic Peninsula and covers much of Clallam and Jefferson Counties. In addition to the large park area inland on the Peninsula, the park also has three coastal districts which account for much of the northern MSP Study Area coastline (Map 1). Olympic National Park is the region's predominant recreation and tourism destination, and receives an estimated 3 million visitors annually, with about 759,000 to 783,000 estimated visitors each year to the three coastal park districts during 2011-2014. Park facilities include coastal public access points, trails, campgrounds, and wilderness campsites (Industrial Economics Inc., 2014).

[4] Total employment and labor income estimates were generated by Taylor et al. (2015) using economic multipliers derived from IMPLAN models based on 2012 regional economic data. For more information see the Socioeconomics chapter and the Cascade Economics report.

Five National Wildlife Refuges are located within the Study Area (Map 1); Flattery Rocks, Quillayute Needles, and Copalis National Wildlife Refuges are offshore and public access to these islands is prohibited, although wildlife viewing from boats is allowed (Industrial Economics Inc., 2014). Grays Harbor and Willapa National Wildlife Refuges are on the mainland and open to visitors. Grays Harbor National Wildlife Refuge is a main attraction in the Grays Harbor/Aberdeen area, where a 1,800 foot boardwalk provides access for viewing the hundreds of thousands of migrating shorebirds visiting the Refuge's muddy tidal flats. Willapa National Wildlife Refuge has several units located adjacent to Willapa Bay encompassing habitat such as salt marsh, muddy tidelands, forest, freshwater wetlands, streams, grasslands, coastal dunes, and beaches. This diversity supports a variety of recreational activities, including wildlife viewing, hiking, hunting, boating, photography, fishing, and shellfish harvesting (Taylor et al., 2015). A study in 2011 estimated 114,680 visits to the Willapa National Wildlife Refuge in 2011, with associated spending totaling and estimated $1.8 million (Industrial Economics Inc., 2014).

State Parks and Public Areas

Washington State Parks and Recreation Commission manages several state parks, the Seashore Conservation Area (SCA) (Map 1), and ocean beach approaches along the coast within Grays Harbor and Pacific counties. Many of the parks have overnight facilities with campground sites, while others are day use only. Approximately 9,220,903 people visited Pacific coast state parks, SCA, and ocean beach approaches in 2013, with an estimated $3,299,696 in revenue. The most popular state managed areas for visitation along the coast are North Beach SCA (1.5 to 2.6 million visitors per year), Long Beach SCA (1.7 to 3 million visitors per year), Cape Disappointment (0.6 to 1.5 million visitors per year), and South Beach SCA (0.7 to 1.3 million visitors per year) (Industrial Economics Inc., 2014).

Public access is critical for supporting and facilitating coastal recreation. In general, there are more public access opportunities in the southern half of the Study Area compared to the northern half (Map 34). Coastal towns, state parks, SCA, and broad sandy beaches are among the main reasons why the public has more opportunities to access the beach in Grays Harbor and Pacific Counties. The remote location, rugged coastline, limited population centers, and tribal reservations limit the opportunity for convenient public access in Jefferson and Clallam Counties, although in some locations, the tribes support and facilitate public tourism and recreation on their reservation lands. The Olympic National Park also has access points, campgrounds, and wilderness campsites for the enjoyment of the coast. While visited less frequently and in more restricted areas, the northern half of the MSP Study Area provides visitors with a unique opportunity to enjoy the remote beauty of the Olympic Peninsula's ocean coast.

Marinas

Marinas and boat launches support public access to the water. (See Map 30) Marinas provide opportunities for private boat owners to launch their boats, as well as support charter operations for bird and wildlife viewing, sightseeing, and fishing. The two marinas in Clallam County that support recreation within the MSP Study Area are owned by tribes - the Makah Tribe (Makah Marina in Neah Bay) and Quileute Tribe (La Push Harbor Marina). There are no marinas for use by the public in Jefferson County in the MSP Study Area. Several marinas and ports provide public access for recreational users in the southern half of the MSP Study Area, including the popular Westport Marina. The Quinault Nation purchased the Ocean Shores Marina but has closed due to needed repairs and dredging. There is a boat launch in the river mouth in Taholah that is only open to tribal members. In Willapa Bay, there are several marinas and public boat launches including, but not limited to: Nacohtta, Bay Center Marina, Tokeland Marina, Raymond Port Dock, and South Bend. Ilwaco and Chinook (on the Columbia River) also have recreational boat access and support users of the MSP Study Area.

Lodging

Lodging is an important part of the coastal infrastructure that both attracts visitors and supports the tourism industry. Lodging options on the Pacific coast of the MSP Study Area include campgrounds, RV parks, motels, hotels, bed and breakfast inns, and rental homes. The Point 97 & Surfrider Foundation (2015) study found lodging expenses as the highest expenditure for coastal trips (averaged $25.96, including those without lodging expenses). The average estimated total annual expenditures for all visitors is approximately $481 million with 22% of that going to lodging - approximately $107 million annually (Point 97 & Surfrider Foundation, 2015).

Highlights in Clallam County include the Hobuck Beach Resort owned by the Makah Tribe, Quileute Oceanside Resort owned by the Quileute Tribe, and campgrounds and wilderness campsites in Olympic National Park. In Jefferson County, Olympic National Park includes the Kalaloch Lodge as well as a variety of campgrounds and wilderness campsites. In Grays Harbor County, the Quinault Nation owns the Quinault Beach Resort and Casino; state parks offer camping, RV camping, and yurts; and the coastal towns and cities offer a variety of lodging. In Pacific County, lodging options include the Shoalwater Bay Casino owned by the Shoalwater Bay Tribe, RV and tent campsites, cabins, and yurts at state parks, and hotels and motels in the coastal cities (Industrial Economics Inc., 2014).

Future Trends

Future trends within the recreation and tourism industry on Washington's Pacific coast are difficult to predict. The industry may be influenced by population growth, development of second home communities, limited access, and water quality issues. These issues that may influence the industry are discussed below.

Population growth and access

The specific recreational activities preferred by visitors to the coast have not changed substantially in recent history. Comparing the results of the Surfrider Foundation recreation survey in 2014-2015 and a Washington State Recreation and Conservation Office report for 2002-2012 shows that out of the top five recreational activities of beach going, sightseeing, camping, hiking, and photography, only the rate of beach going changed significantly with increasing rates (as cited in Taylor et. al, 2015). New trends in recreation are growing on the coast of the MSP Study Area, including stand up paddleboarding and kite surfing, showing continued demand for access.

Between 2015 and 2025, total population growth in the coastal counties is projected to average nine percent, and statewide growth is predicted at eleven percent (as cited in Taylor et al, 2015). While it can be inferred that an increase in population would lead to an increase in demand for recreation and tourism activities and facilities, this growth may be restricted by limited access to some areas of the Pacific coast. As discussed above, the northern half of the study area has fewer public access opportunities than the southern half of the study area. Although there are many opportunities for access to the beach along the southern coast, anecdotal evidence shows that during peak periods certain facilities lack sufficient parking to handle large crowds. Population growth and the increasing popularity of certain activities may increase overcrowding (Taylor et al., 2015).

Environmental factors

The potential exists for a variety of environmental issues to impact the recreation and tourism industry in the future. Potential erosion, particularly along the southern coast, could impact recreation facilities and access to recreation and port facilities. Water quality is also a concern, past issues have impacted recreational users of ocean resources and the potential exists for future effects as well. The razor clam fishery, a highly popular recreational activity, has had frequent closures due to harmful algal blooms. Marine algae blooms have also killed birds and caused health symptoms among surfers on coastal beaches (Industrial Economics Inc., 2014).

Similar to the concerns highlighted in the Fisheries chapter, local stakeholders are also concerned about the potential for oil spills to threaten coastal recreational resources. The impacts of an oil spill on the natural resources of the Pacific coast could affect the recreation and tourism industry for an extended period of time.

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2.7 Marine Transportation, Navigation, and Infrastructure

Marine shipping, transportation, and the associated infrastructure are significant uses of the MSP Study Area. Although this report is focused on the MSP Study Area, it is impossible to discuss marine transportation, navigation, and infrastructure without recognizing the relationship to activity in the Strait of Juan de Fuca, Puget Sound, and coastal points north and south of the Study Area. It is also challenging to separate out the economic impacts of these uses for just the Study Area as most studies and economic forecasts encompass broader areas. Therefore, this discussion of marine transportation, navigation, and infrastructure will often highlight impacts to the larger region.

This chapter summarizes the history and current use, economic impacts, and future trends of marine transportation, navigation, and associated infrastructure in the MSP Study Area.

Summary of History and Current Use

Shipping

Early trade began with Native peoples along the coast traveling widely by water, expanded with the introduction of European explorers focused on the region's natural resources, and continued to grow into the 18th and 19th centuries as competition for the northwest and its trade resources intensified. Washington eventually developed as an exporter of raw materials with well-developed trading networks (Washington Department of Archaeology and Historic Preservation, 2010). Settlers were drawn to the region due to the availability of natural resources and potential for trade with important early exports in lumber, shingles, and high-grade coal. Railroad companies developed a monopoly on moving cargo and received grants of federal land, with state and local governments often providing further land concessions leading the railroads to own large parcels of prime waterfront property (Caldbick, 2010).

As a response to the railroad monopoly, Washington passed the Port District Act of 1911 that allowed voters to create and form public port districts that were required to devote their efforts and resources to developing and operating harbors and related facilities for public benefit. They also had the power to levy taxes, incur debt, and take land through eminent domain. Within 15 years of the Port District Act, all 11 of the state's currently operating deep-draft ports had been established including the ports of Grays Harbor, Seattle, and Tacoma. The ports and trade generally prospered during World War I and World War II, and suffered challenges during each transition to a postwar economy. Over time, the ports became more technically sophisticated and were able to handle a greater variety of cargoes with reduced effort and expense. The Port of Grays Harbor is the only deep-draft port in the MSP Study Area. Although the Port of Grays Harbor took 11 years to open its first public deep-draft pier and terminal in 1922, by 1924 more than one billion board feet of lumber exports passed through the port (Caldbick, 2010). Today the Port of Grays Harbor has four terminals and five deep-draft berths with direct access to railroad lines. The primary imports and exports are liquid- and dry-bulk cargo and automobiles.

A report by BST Associates (2014), describes cargo shipping transits and provides projections for the Pacific Northwest (PNW) Gateway which includes 11 seaports, airports, and international land crossings for the states of Washington and Oregon.[1] The PNW Gateway accounted for $204 billion dollars of goods in international trade in 2013. The PNW is the key gateway for goods moving between the United States and Asia and totals 13% of waterborne U.S.-Asia trade. The PNW was also the sixth largest gateway for waterborne trade of exports of American products based on 2013 export value. The largest

[1] Throughout this section, Pacific Northwest (PNW) refers to Washington and Oregon.

trading partners through PNW ports for waterborne trade are China (31%), Alaska and Hawaii (23%), Japan (18%), and South Korea (6%) (BST Associates, 2014).

Marine traffic through the MSP Study Area is highly influenced by trends and shifts in trade patterns throughout the United States and the world that dictate the traffic flow through the ports in Puget Sound, the Columbia River, and the Pacific Coast. Container traffic in the PNW region, through Tacoma, Seattle, and Portland, saw strong growth through 2005, but then experienced a decline due in part to the economic recession and competition from other ports. Container volumes began to recover in 2011, remained flat in 2012-2013, and are projected to grow slowly at a rate of 2.2 percent annually from 2013-2035. However, even as container volumes have recently increased, container vessel traffic has continued a slight decline, due largely to the increasing size of container vessels (BST Associates, 2014).

Cargo shipments

Grain exports in the PNW are primarily handled through Columbia River ports. However, world competition in the market is intense and the volume of corn available for export has reduced due to increased domestic demand for use in ethanol production. Soybean exports through the PNW have increased and there continues to be strong demand for vegetable oils. Upgrades at port facilities on the Columbia River and at Grays Harbor have improved the grain elevator capacity. Annual exports of grain and oilseeds through PNW ports doubled between 2002 and 2010 from less than 16 million metric tons to nearly 33 million metric tons. Growth is projected at 2.2 percent annually from 2013 to 2035 (BST Associates, 2014)

Key dry bulk commodities at Puget Sound and coastal ports include scrap metal, wood chips, sand and gravel, cement, and gypsum. Columbia River exports include minerals, ores, chemicals and fertilizers, petroleum by-products, and wood chips. Since 2000, dry bulk shipments has had generally slow growth in volume and is projected to continue to grow at 1.3 percent per year from 2013 to 2035 (BST Associates, 2014). This forecast could change substantially with increases in dry bulk shipments of coal or potash if potential projects on the Columbia River or Puget Sound move forward (BST Associates, 2014).

Liquid bulk commodities in the PNW are primarily petroleum, including crude oil and refined products, with handling of much smaller volumes of other liquids like chemicals and fertilizers. The Port of Grays Harbor handles mainly biodiesel which includes the byproducts of methanol and glycerin while ports in the Columbia River handle petroleum products and chemical products. In addition to the existing volume of shipments, there are multiple projects that are in the planning or permitting stages that could substantially increase the volume of shipments. These include crude oil rail-to-vessel transfer facilities in Grays Harbor (discussed further in future trends section below), and Columbia River ports. Additional facilities are proposed for methanol production and export on the Columbia River and LNG export at Ferndale. The volume of liquid bulks transported by vessel has decreased over the past decade. The decrease was driven by a reduction in receipts of crude oil from Alaska as production has decreased there and been replaced by other sources including crude oil coming to the PNW by rail from North Dakota. Waterborne movements of petroleum products are projected to decline from 2013-2035 with an average annual growth rate of -0.4 percent. This does not include the potential future projects which could increase the shipments (BST Associates, 2014).

Other major PNW commodities include automobiles, lumber, heavy machinery, bundled metal, and scrap steel (referred to as neobulk[2]) and logs, forest products, and other project cargoes like wind turbines, and heavy equipment parts (referred to as breakbulk[3]). The majority of PNW automobile imports are handled at Columbia River ports, some through Tacoma, and more recently the Port of Grays Harbor, which now handles exports of Chrysler vehicles. Log exports have been relatively strong in the past few years as a result of growing demand in China, Japan, and Korea. Breakbulk exports of forest products like lumber, pulp, and paper have declined significantly, however there was an increase in 2013. Steel breakbulk shipments declined significantly with the downturn in U.S. commercial and residential construction markets but have begun to rebuild slowly. The economic recession caused breakbulk and neobulk trade to bottom out in 2008, with vehicle imports especially impacted. Since 2008, volumes have recovered and exceed the pre-recession level. Volumes are expected to continue to grow slowly at an annual rate of 0.7 percent through 2035 (BST Associates, 2014).

Vessel traffic

Vessel types transiting the MSP Study Area include tank vessels that carry bulk liquids like oil, methanol, biodiesel, and vegetable oil. Tank vessels are tank barges that are propelled using a tug and self-propelled tankers. Cargo vessels carry dry goods like grain and wood and include self-propelled cargo ships, cargo barges that are propelled using a tug, and RoRo vessels (roll-on/roll-off) that carry automobiles or other wheeled vehicles (City of Hoquiam & Washington State Department of Ecology, 2016). Passenger vessels such as cruise ships also transit the study area occasionally. Patterns of use by other vessels such as fishing and recreational uses are described other chapters (Section 2.4 Fisheries and Section 2.6 Recreation and Tourism).

Vessels are defined by their carrying capacity or deadweight tonnage (dwt), or the number of metric tons that a vessel can transport of cargo, stores, and bunker fuel. Tankers calling in the PNW range from 12,000-190,000 dwt. In Puget Sound, tankers carrying crude oil and products are limited to 125,000 dwt. There is no regulatory tonnage limit for tankers operating in Grays Harbor or the Columbia River. The depth of the navigation channel for the Columbia River and Grays Harbor does limit the size of vessel used in these areas. Crude oil and products are also handled by integrated tug-barges (ITB)[4] and articulated tug-barges (ATB).

The average size of vessels calling in PNW ports increased 2-3 percent annually for most vessel types between 2002 and 2011 based on the average deadweight tons per call. Container vessels calling at PNW ports range from 1,000 to 5,000 TEU[5] ships that serve Alaska, Hawaii, and smaller international trade routes. Container vessels in Pacific trade have increased in size, with shipping lines increasing from 5,000 TEU to over 10,000 TEU vessels. The growing size of the container ships for efficiency has meant a decrease in the number of container ship calls and this is expected to continue or level out in the future (BST Associates, 2014).

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[2] Neobulk includes general cargo that is prepackaged, counted, and loaded individually, not in containers, and transferred as units at the terminal.

[3] Breakbulk includes general cargo that is loaded in bulk units and either packaged in boxes or barrels or attached to pallets or skids, not in containers, and transferred at the terminal.

[4] There have not been any ITBs in the Puget Sound region for years (Veentjer, J., personal communication, February 6, 2017).

[5] The 20-foot equivalent unit (TEU) is the standard industry measurement for containers. However, containers come in several sizes and most in use today are 40-foot containers (Washington State Department of Commerce, 2014).

The number of vessel calls in the PNW is forecast to decline to 3,336 vessel entrances in 2035. The number of vessel calls peaked in 1996 at 5,431 and fell to 3,947 in 2013. This decline was due in part to increased vessel size, and average to a -1.9 percent trend per year. Between 2013 and 2035 the forecast of a decline of 611 vessel calls averages to -0.8 percent per year. This prediction is based on historical trends from Ecology Vessel Entries and Transits reports and Marine Exchange of Puget Sound data for Puget Sound and Grays Harbor. This does not include any of the projects in the planning or permitting stages that could increase the volume of dry bulk or liquid bulks shipped through the PNW (BST Associates, 2014). If the proposed projects move forward there is the potential for significant increases in vessel traffic.

There are a number of maps that show the density of the different vessel types in the MSP Study Area: cargo vessel density (Map 35), passenger vessel density (Map 36), tanker vessel density (Map 37), and tug and tow vessel density (Map 38).

Navigation

The variety of vessel types and density of vessels transiting the MSP Study Area necessitates a number of schemes that are designed to guide vessel paths through the area to avoid conflicts. These are discussed below and the shipping lanes, federal navigation channels, and navigation agreement lanes are highlighted in Map 39.

The U.S. Coast Guard (USCG) maintains aids to navigation (ATON) within the MSP Study Area, which include a mixture of lateral and non-lateral buoys, beacons, and automated identification system (AIS) (USCG, personal communication, February 7, 2017). The USCG also maintains lighthouses at Cape Flattery, North Head, Grays Harbor, and Cape Disappointment (United States Coast Guard, 2016c).

Vessel Traffic Service Puget Sound, maintained by the U.S. Coast Guard functions to facilitate good order and predictability on the Salish Sea waterways by coordinating vessel movements through the collection, verification, organization, and dissemination of information (USCG, personal communication, February 7, 2017). Vessels can be tracked for informational purposes using AIS that are required on all large commercial vessels (City of Hoquiam & Washington State Department of Ecology, 2016). The U.S. Coast Guard works cooperatively with the Canadian Coast Guard's Marine Communications and Traffic Services (MCTS) to manage vessel traffic in adjacent waters to cover offshore approaches and all of the Salish Sea (U.S. Coast Guard Navigation Center, 2016). The Marine Exchange of Puget Sound (MXPS) monitors arriving and departing commercial vessels in the Puget Sound region and Grays Harbor. The MXPS does not proactively track or monitor vessels offshore, but has the capability to do so out to about 50 miles (Veentjer, J., personal communication, February 6, 2017). The Merchants Exchange of Portland also monitors arriving and departing commercial vessels in the Columbia River and has the capability to do so out to about 50 miles off the Washington and Oregon coasts (Veentjer, J., personal communication, February 6, 2017).

Traffic separation schemes (TSS) are designed to establish traffic lanes that separate opposing streams of traffic. There are TSS designated for the approaches to the Strait of Juan de Fuca including a western approach, the southwestern approach, and a precautionary area. Additional TSS are designated for within the Strait of Juan de Fuca, approaches to Puget Sound, and within Puget Sound. Washington Sea Grant worked with towboaters and crab fishermen to establish towboat lanes along the Pacific Coast between San Francisco, CA and Cape Flattery, WA. The towboat lanes are designed to limit interactions between fishing gear and towing vessels that can destroy the gear and foul the propellers and shafts of the towing vessels (National Oceanic and Atmospheric Administration, 2016).

The Olympic Coast National Marine Sanctuary (OCNMS) encompasses much of the northern half of the MSP Study Area. Prevention of spills of oil or other hazardous material from a major marine accident is one of OCNMS' highest priorities as such a spill would be a threat to the resources and qualities of the sanctuary. The International Maritime Organization (IMO) designated an Area to Be Avoided (ATBA) within the OCNMS (Map 39). The IMO establishes ATBAs in defined areas where navigation is very hazardous or where it is important to avoid casualties. The ATBA recommends certain classes of vessels in-transit to stay outside of the defined area. It is a voluntary program that applies to ships and barges carrying oil or hazardous materials as cargo and all ships 400 gross tons and above that are solely in transit. Voluntary compliance is very high. The ATBA does not apply to vessels engaged in activities like fishing and research that are otherwise allowed in the sanctuary. It also does not apply to government vessels, but they are encouraged to avoid the area when solely in transit (Olympic Coast National Marine Sanctuary, 2015).

Most deep draft vessels and barges carrying liquid bulks (petroleum, petroleum products, biofuels and chemicals) travel well offshore unless they are entering or departing a port. However, barges and vessels that are accessing the Port of Grays Harbor, and barges that are carrying dry cargoes (regardless of destination) do transit the coastal area just below the Area to Be Avoided (ATBA). This is a consideration for development of offshore energy systems (BST Associates, 2014). The Grays Harbor Navigation Channel is nearly 23 nm long, begins approximately 4 miles offshore and runs in an easterly direction allowing access for deep-draft vessels to the Port of Grays Harbor facilities (City of Hoquiam & Washington State Department of Ecology, 2016). All deep-draft vessels are limited by the depth of the navigation channel in Grays Harbor.

The West Coast Offshore Vessel Traffic Risk Management Project Workgroup[6] recommends that, where no other management measure such as ATBAs, Traffic Separation Schemes (TSS), or recommended tracks already exist, vessels 300 gross tons or larger transiting coastwise anywhere between Cook Inlet, AK and San Diego, CA should voluntarily stay a minimum distance of 25 nautical miles (nm) offshore. They also recommend that with those same management exceptions, tank ships laden with crude oil or persistent petroleum products should voluntarily stay a minimum distance of 50 nm offshore (West Coast Offshore Vessel Traffic Risk Management Project Workgroup, 2002). AIS data, as seen in Maps 35, 36, 37, and 38, indicate that most of the vessels transiting the MSP Study Area do stay offshore as recommended. Exceptions to this include vessels entering and exiting Grays Harbor and Willapa Bay as well as smaller vessels including tug/tow vessels.

Ship and boat building, maintenance, and repair

The ship and boat building, maintenance, and repair sector of the maritime industry includes new construction, maintenance, refurbishment, and modernization of commercial, recreational, and military vessels. This sector has a long history in Washington with a great demand for shipbuilding as the timber industry drove early shipping and Seattle developed as a trade and shipping center. Another center for trade developed on Puget Sound when Tacoma was chosen as the western terminus of the Northern Pacific Railroad's transcontinental line. As a result, shipyards began to establish themselves on Puget Sound (Community Attributes Inc., 2013).

The majority of this industry is centered outside the area adjacent to the MSP Study Area. The commercial companies in this sector are larger, but there are fewer of them, while the recreational

[6] The West Coast Offshore Vessel Traffic Risk Management Project was co-sponsored by the Pacific States/British Columbia Oil Spill Task Force and the U.S. Coast Guard, Pacific Area. The full report and workgroup membership are available at: http://oilspilltaskforce.org/.

companies are smaller but more numerous. The Puget Sound Naval Shipyard in Bremerton is the largest and most diverse shipyard on the west coast, and has more than 11,000 civilian employees (Community Attributes Inc., 2013).

One example of this sector in the MSP Study Area is the Westport Shipyard. The Westport Shipyard in Grays Harbor was founded in 1964 and began by building oceangoing vessels for the Pacific commercial fishing fleet but now specializes in yacht and commercial construction. In addition, the company has a shipyard in Port Angeles, WA and a yacht sales center in Fort Lauderdale, FL. Since the founding of the shipyard, the total vessels built by Westport include over 100 recreational yachts, 170 commercial fishing vessels, 35 commercial passenger vessels, and 7 other commercial vessels. The Westport Shipyard is a 170,000 square foot enclosed facility, the Port Angeles shipyard is a 100,000 square foot enclosed facility, and there are an additional cabinet shop and upholstery shop supporting the operation (Westport, 2016).

In addition to the larger boat building operations, there are a number of locally important, smaller facilities in the ports and marinas within or directly adjacent to the MSP Study Area that support boat haul out and repairs. These facilities are important to the operation of other sectors including fishing and aquaculture.

Economic Impact

Marine transportation and shipping has an economic impact on the coastal counties adjacent to the MSP Study Area. It is challenging to try to isolate the impacts to just the coastal counties, because vessels transiting through the MSP Study Area are coming from and bound for a variety of locations, including the Puget Sound or Columbia River ports, which are part of the total ocean economy for the state.

Washington State

Community Attributes Inc. performed an economic impact study of the maritime cluster in Washington in 2013. They define the maritime cluster to include six core sectors, including maritime logistics and shipping; ship and boat building, maintenance, and repair; maritime support services; passenger water transportation; fishing and seafood processing; and military and other federal operations. The focus of this chapter is on the first three sectors listed, but the economic information covers all six sectors. For Washington in 2012, the entire maritime cluster directly employed more than 57,700 people in the state, and was responsible for $15.2 billion in gross business income (Community Attributes Inc., 2013).

The subsectors relevant to this chapter include maritime logistics and shipping which includes port and harbor operations, deep and shallow water goods movement, inland water freight transport, and refrigerated warehousing and storage. Boat and ship building, repair, and maintenance includes new construction of vessels, maintenance, refurbishment and overhaul, and modernization. Maritime support services include support for commercial, recreational, and defense-related maritime activities like boat dealers, marinas, fueling and lubricant businesses, engineers, naval architects, parts suppliers, and construction. Table 2.7-1 summarizes the maritime impacts of these subsectors throughout Washington.

Table 2.7-1: Summary of economic impacts from maritime subsectors in Washington State. Source: Community Attributes Inc., 2013.

Maritime subsector	Employer establishments	Wages ($ millions)	Jobs	Gross business income ($ millions)
Maritime logistics and shipping	800	1,156.0	16,700	3,722.4
Maritime support services	300	387.7	4,600	864.2
Boat and ship building, repair, and maintenance	150	1,163.8	16,500[7]	1,489.7
Fishing and seafood processing	720	1,113.4	15,400	8,592.6
Passenger water transportation	130	262.8	4,500	544.5
Total	2,100	4,083.7	57,700	15,213.3

Coastal counties

A separate economic analysis, Economics: National Ocean Watch (ENOW), was conducted by the NOAA Coastal Services Center using data from 2005-2011. ENOW describes six economic sectors that depend on the ocean: living resources, marine construction, marine transportation, offshore mineral resources, ship and boat building, and tourism and recreation. The ENOW analysis describes the ocean economy at the county level and shows the contribution of the five Pacific coastal counties (Clallam, Jefferson, Grays Harbor, Pacific, and Wahkiakum) to Washington's ocean economy. These five counties accounted for 6 percent of employment and 3.9 percent of GDP in the statewide ocean economy. The impact of the marine transportation sector in the Pacific coastal counties as compared to the impact statewide is displayed in Table 2.7-2.

Table 2.7-2: Marine transportation contribution to the ocean economy of the five Pacific Coast counties and statewide. Source: NOAA Coastal Services Center, 2014.

Marine Transportation	Pacific Coast Counties[8]	Statewide
Establishments	6	409
Employment	63	19,105
Wages (thousands of dollars)	4,523	1,279,000

[7] Included in this subsector are more than 11,000 civilian jobs at the Puget Sound Naval Shipyards in Bremerton.

[8] These numbers are reported for the five Pacific Coast Counties, and not by individual county, due to data confidentiality requirements. Where the number of establishments is low in one county, the data is suppressed, allowing results for only the larger coastal area to be shown. In Jefferson and Clallam counties, it is likely the analysis overestimates the numbers for establishments directly adjacent to the MSP Study Area. This includes the entire county, so information from establishments on the Strait of Juan de Fuca and Puget Sound is included.

Average wages	71,794	66,961
GDP (thousands of dollars)	7,976	2,594,000
Self-employed workers	40	523

Port of Grays Harbor

The Port of Grays Harbor is a major economic driver for coastal Washington and also has economic impacts in other parts of the state. Port of Grays Harbor facilities support the movement of waterborne cargo into and out of the state. In total, 2.38 million metric tons of cargo moved through Port of Grays Harbor facilities in 2013. This included soy meal and other bulk commodities, automobiles, forest product exports in chips and logs, and liquid bulk (Martin Associates, 2014). Table 2.7-3 estimates the economic impact based on five commodities; wood chips, grain, automobiles, logs, and liquid bulk at 2013 levels. Table 2.7-3 shows 574 direct jobs and $143.5 million of direct business revenue generated by these five commodities through the port. Of the 574 direct jobs, 94 percent were held by Grays Harbor residents (Taylor, Baker, Waters, Wegge, & Wellman, 2015).

Table 2.7-3: Economic impacts of cargo activity at Port of Grays Harbor marine terminals. Source: Martin Associates, 2014.

Category	
Jobs (number)	
Direct	574
Indirect	645
Induced	305
Total Jobs	1,524
Personal Income ($1,000)	
Direct	$36,239
Induced	$79,654
Indirect	$14,860
Total Income	$130,754
Business Revenue ($1,000)	$143,488
Local Purchases ($1,000)	$31,513
State and Local Taxes ($1,000)	$12,291

The Port of Grays Harbor marine cargo terminals have a total revenue impact of $143 million, $118 million of which can be allocated to specific commodity types (Table 2.7-4). Much of this revenue can be tied to the state of Washington through payment of salaries and wages, purchase of local goods and services, and the payment of state and local taxes. However, the revenue also has a national and international impact beyond those uses. The impact of the specific commodities being shipped through the Port of Grays Harbor can also be seen through the distribution of direct revenue impact. The greatest revenue on a per ton/revenue basis is generated by handling of autos followed by grain. The majority of the revenue generated by autos and grain is in the surface transportation sector followed by terminal operations (Martin Associates, 2014).

Table 2.7-4: Revenue impact by commodity generated by the Port of Grays Harbor marine cargo terminals. Source: Martin Associates, 2014.

Commodity	Direct Revenue ($1,000)	Tonnage Metric Tons	Revenue 1,000 Tons
Chips	$1,130	94,732	$11.93
Grain	$69,186	1,360,611	$50.85
Autos (units)	$32,513	92,790	$350.39
Logs	$5,165	317,390	$16.27
Liquid bulk	$10,241	433,981	$23.60
Not allocated	$25,253		
Total	$143,488		

The Port of Grays Harbor and other ports outside of the MSP Study Area face competition from each other, ports on the west coast, and even the east and gulf coasts. Shifts in the trade patterns have the potential to cause economic impacts within the areas adjacent to the MSP Study Area.

Related Infrastructure

Ports and marinas

There are a number of ports and marinas adjacent to the MSP Study Area that provide a variety of functions including moorage and access for recreational and commercial fishing vessels, fish processing, shipping and storage, and vessel and gear maintenance. An overview of the ports and marinas is provided here, with further detail on fishing related functions available in the Fisheries chapter and dredging requirements in the Dredging and Dredge Disposal chapter.

Some of the ports discussed below are outside of the MSP Study Area, including the Port of Neah Bay, Port of Ilwaco, and the Port of Chinook. These ports and marina all provide critical services important to uses within the Study Area and contribute significantly to the coastal economy.

Clallam County ports

Neah Bay

The Makah Tribe owns and operates the Makah Marina in Neah Bay, which primarily serves as a fishing marina and dock. The facility has undergone recent upgrades that are expected to help retain fishing related jobs and also improve oil spill response capabilities by providing a safe dock for response vessels. Upgrades to the dock included building a new concrete dock and a new facility with offices, a hoist, an ice plant, and two icing stations (Taylor et al., 2015). The Makah Marina at Neah Bay is protected from waves by an Army Corps of Engineers maintained riprap wave barrier. The marina has 200 slips and caters mostly to private boats. It is open for recreational use from April through September. The USCG operates a small boat station just east of the marina.

Quileute Harbor Marina

The Quileute Harbor Marina, owned and operated by the Quileute Tribe and located in La Push, is the only designated safe harbor between Neah Bay and Westport. The marina has 95 slips, some of which are leased to commercial and recreational fishermen. The U.S. Coast Guard uses the marina as homeport for the Quillayute River Station, the only search and rescue station between Grays Harbor and Neah Bay. In 2014, the marina underwent improvements including plank replacement on existing docks and construction of a new boat ramp that will allow for removal of larger vessels. The Army Corps of Engineers also performed some dredging of the Quillayute River at the harbor. The west end of the marina has facilities that the tribe leases to High Tide Seafoods including a high dock with a lift, ice machine, and space for a fish processing plant in La Push and it serves tribal and non-tribal fishers (Taylor et al., 2015).

Jefferson County ports

Jefferson County does not have any ports or marinas on the coast in the MSP Study Area. The Port of Port Townsend and other marinas are located on Puget Sound.

Grays Harbor County ports

Port of Grays Harbor

The Port of Grays Harbor is the only deepwater port on the Pacific Coast of Washington. It is also two days of travel time closer to Asia than Puget Sound ports, which gives it a locational advantage promoting expansion beyond traditional commodity shipments (Taylor et al., 2015). The Port of Grays Harbor was the second Port District to be created in the state in 1911, after the Port District Act passed earlier in the year. The Port's first facility, Pier 1, opened in 1922. For several years in the 1920s, Grays Harbor was the largest lumber exporting port in the world with exports exceeding a billion board feet annually. Lumber exports continued to provide the bulk of the Port's business into the 1980s. After a dramatic reduction in logging in the 1980s-1990s, the Port worked to diversify its business (Ott, 2010). The Port did this by undergoing a dredging project to accommodate oceangoing vessels that continue to grow in size and by maintaining a connection with two Class 1 Railroads via an agreement with a shortline railroad which allowed for the development of a bulk handling facility and automobile export operation (Ott, 2010). The Westport Marina, a facility of the Port of Grays Harbor, is the number one seafood landing point in Washington. The Port of Grays Harbor is the number one exporter of American grown soybean meal (Taylor et al., 2015). The Port has diversified and now includes automobiles, biodiesel, other liquid, dry bulk, and overhigh/overwide (OHOW)[9] products among goods shipped.

The Port of Grays Harbor operates four marine terminals at the eastern end of Grays Harbor that are supported by secure cargo yards, an on-dock rail system, and covered storage. Terminal 4 is the main general cargo terminal and the largest, with a 1,400 ft. long berth that can handle two vessels and serves as the primary Ro/Ro and breakbulk cargo terminal. Terminal 3 is a deep water terminal with on-site rail. Terminal 2 is a dry and liquid bulk facility that is served by a rail loop. Terminal 1 is a barge and liquid loading facility with an on-site rail loop (Port of Grays Harbor, n.d.).

Westport Marina

The Westport Marina is a 550 slip marina owned and operated by the Port of Grays Harbor. It is home to a large commercial fishing fleet and recreational fishing vessels, including the state's largest charter fishing fleet. Current annual moorage rates show 94 recreational vessels and 188 commercial fishing vessels. There is also a boat launch for private boats and boat trailer parking. (Taylor et al., 2015). The USCG operates a small boat station which is located at the south corner of the marina.

Quinault Marina

The Quinault Nation owns the Ocean Shores Marina but it is currently closed due to needed repairs and dredging (Taylor et al., 2015).

Pacific County ports

Port of Peninsula

The Port of Peninsula owns a commercial facility in Nahcotta, WA located on the Willapa Bay side of the Long Beach Peninsula. The Port District serves the oyster, clam, and crab industries, a gillnet fleet, and recreational users with 90 slips and a public boat launch. In 2009, the port rebuilt the service pier providing the shellfish industry on Willapa Bay with a modern, environmentally responsible, and secure facility to support business expansion and improve productivity. The service pier provides the only fuel service on the bay and utilizes an above-the-ground storage tank (M. Delong, personal communication, October 8, 2014). The Port also sponsors the Willapa Bay Oyster House Interpretive Center, an interpretive center focused on the local oyster industry. Twenty-five percent of the nation's oysters go through the Port of Peninsula (Coast & Harbor Engineering, 2011; Cook, 2012). Increased Manila clam and oyster production in Willapa Bay have elevated the Port to a major landing facility for the region (M. Delong, personal communication, October 8, 2014).

Willapa Bay

The Port of Willapa Harbor was formed in 1928, and developed port facilities for shipping lumber and other forest products as well as fishing and oyster vessels. The Port of Willapa Harbor owns and operates three water access facilities within Willapa Bay: the Raymond Port Dock, Tokeland Marina, and Bay Center Marina.

The Raymond Port Dock has a 50,000 square foot "high dock" that services commercial vessels. There is an additional 700 feet of floating docks available for moorage (Port of Willapa Harbor, n.d.-b). The Bay Center Marina provides moorage for oyster barges and fishing vessels, with capacity for

[9] Overhigh/overwide cargo products are handled specially, not normally a full cargo, and can be added to both neobulk and breakbulk vessels.

approximately 40 vessels. The Bay Center Marina is located within the navigation channel of the Palix River and requires regular dredging to maintain viability as a marina (Port of Willapa Harbor, n.d.-a).

The Tokeland Marina is located at the north end of Willapa Bay and offers recreational and commercial moorage with over 1,000 feet of floating dock. There is also a public fishing pier and boat ramp. The marina and entrance channel experience significant sedimentation and the Port of Willapa Harbor has launched a maintenance dredging program in Tokeland to maintain the dredging previously done by the U.S. Army Corps of Engineers (Port of Willapa Harbor, n.d.-c).

South Bend has a recreational dock for canoeing, kayaking, and fishing as well as a boat launch (Taylor et al., 2015). South Bend also has commercial fish landings directly at seafood processors in the area.

Ilwaco and Chinook

The Port of Ilwaco is located in the southwest corner of Washington just inside the Columbia River. The Port serves commercial fishermen, recreational boaters, two major seafood processing businesses, and a U.S. Coast Guard Station. The Port serves vessels from Washington, Oregon, Alaska, and Canada with an 800-slip marina (Pacific County Economic Development Council, 2013; G. Glenn, personal communication, October 22, 2014). In 2013, 23,720 private trips were launched from Ilwaco, a popular sport fishing port. Facilities at the port include a boat launch, two small boat hoists, and two fuel docks (Taylor et al., 2015).

The Port of Chinook is located on the southwest corner of Washington, a few miles up the Columbia River from the Port of Ilwaco. The Port of Chinook is home to recreational and commercial fishing boats as well as a major crab cannery facility (Pacific County Economic Development Council, 2013). The Port has 300 slips and can accommodate commercial and sport fishing vessels up to 60 feet in length. Additional facilities include a boat launch, boat hoist, and a fueling facility (Taylor et al., 2015).

Emergency Response

United States Coast Guard

The USCG Station Grays Harbor has the Coast Guard's first on water response responsibility over the area ranging from Queets River south to the Long Beach Peninsula, including Willapa Bay. The station has four vessels that perform search-and-rescue activities. The U.S. Coast Guard Captain of the Port of Sector Columbia River, whose office is located in Astoria, Oregon, has the authority to close the bar at Grays Harbor due to severe weather that makes it unsafe for vessels to transit (City of Hoquiam & Washington State Department of Ecology, 2016).

USCG Station Cape Disappointment is in Ilwaco at the mouth of the Columbia River. It is the largest search and rescue station on the Northwest Coast with 50 crewmembers. The station has five search and rescue boats and provides search and rescue to commercial and recreational mariners within 50 nm of the Columbia River entrance. This area is one of the most dangerous river bars in the world and the crewmembers respond to 300-400 calls for assistance each year (United States Coast Guard, 2016b). Station Cape Disappointment and Station Grays Harbor are units of the USCG Sector Columbia River with headquarters in Warrenton, Oregon. The headquarters has more response assets available that individual stations. Sector Columbia River's area of responsibility includes 420 nm of coastline in Washington and Oregon and the Columbia River (United States Coast Guard, 2016a).

USCG Station Quillayute River is located in La Push on the Quileute Tribe's reservation. The station has two lifeboats to respond to emergency calls in the area between Cape Alava and Queets River. The station is supported by USCG Air Station/Sector Field Office Port Angeles.

USCG Station Neah Bay has life boats to respond to emergencies from Cape Alava to the northern extent of the MSP Study Area.

Emergency towing vessel

There is an emergency response towing vessel (ERTV) permanently stationed at Neah Bay and available to assist vessels off the coast of Washington or in the Strait of Juan de Fuca. Any "covered" vessels,[10] essentially tank vessels, cargo vessels, and passenger vessels, that are transiting to or from a Washington port through the Strait of Juan de Fuca are required to include the towing vessel in Neah Bay in their oil spill emergency response plans (City of Hoquiam & Washington State Department of Ecology, 2016). The ERTV is industry-funded to be on station in Neah Bay and available for hire 24 hours a day to assist vessels having maneuvering issues (e.g. propulsion and steering problems) or vessels that are directed by the U.S. or Canadian Coast Guards to obtain towing or escort assistance (National Oceanic and Atmospheric Administration, 2016). More than 90% of the assistance provided has been escorting, often as required by the U.S. Coast Guard (J. Veentjer, personal communication, February 6, 2017).

The tug is intended to be able to make up to, stop, hold, and tow a drifting or disabled vessel of 180,000 metric dead weight tons in severe weather conditions (National Oceanic and Atmospheric Administration, 2016). The ERTV could assist with vessels in a difficult situation in or near Grays Harbor, however, under normal weather conditions, it could take an average of 12 hours to reach the harbor and under adverse weather conditions, transit time to Grays Harbor could be as much as 18 hours. Tugs currently operating on the Columbia River could provide the same assistance; travel time would be approximately 12 hours to Grays Harbor.

Since 1999, the ERTV has been deployed to either stand by or directly assist 54 vessels that were either completely disabled or had reduced ability to maneuver. The types of vessels assisted have included deep draft cargo vessels, large fish and fish processing vessels, fully laden oil and chemical tank ships, and tugs with tank barges in tow. During 14 of these responses, the ERTV had to tow the disabled vessels to prevent them from drifting onto the rocks and spilling oil. The potential combined oil spill for those 14 cases is over 3 million gallons (Washington State Department of Ecology, 2016).

Future trends

Shipping

For Washington and Oregon, waterborne cargo volumes are projected to continue growing at modest rates. Overall growth is projected to average 1.3 percent per year between 2013 and 2035 across all cargo types. However, the number of vessels is predicted to continue to decrease as companies shift to using larger vessels and therefore require fewer vessels (BST Associates, 2014).[11]

[10] RCW 88.46.010(5) defines covered vessel as "…a tank vessel, cargo vessel, or passenger vessel." The RCW further defines a cargo vessel as "…a self-propelled ship in commerce, other than a tank vessel or a passenger vessel, of three hundred or more gross tons, including but not limited to, commercial fish processing vessels and freighters." It also further defines passenger vessels as "…a ship of three hundred or more gross tons with a fuel capacity of at least six thousand gallons carrying passengers for compensation."

[11] The average size of deep-draft vessels calling at the Port of Grays Harbor has increased on average by 3.2 percent per year between 2005 and 2012, from 28,300 tons to 35,300 tons (BST Associates, 2014).

These predictions are not specific to the coast of Washington, but also include Puget Sound, Columbia River, and Oregon ports. It is hard to predict impacts for individual Pacific coast ports and activities based on projections for the larger area.

Changes in world trade patterns may affect trade flows through the PNW. Trade with China is being affected by economic shifts including rising wages and an increasing exchange rate. If multinational firms decide to relocate production away from China, this could shift waterborne container trade and decrease the trade moving through the PNW. So far, there has only been a modest shift in trade routes and it is unknown how this will change in the future. This potential loss of cargo trade may be offset by exports of containerized and non-containerized products from the PNW to China as a result of rising incomes in China stimulating increased consumption of U.S. products (BST Associates, 2014).

Cargo forecasts for specific commodities for the PNW include a 2.2 percent increase in grain and oilseed exports between 2013 and 2035. There have been significant increases in grain and oilseed exports due to increased demand in Asia, increased production, and favorable ocean freight rates (BST Associates, 2014). Neobulk, including automobiles and logs, is an important component of Grays Harbor trade and is predicted to grow annually at 0.7 percent through 2035. For liquid bulk, the largest volumes in the PNW are in crude oil and refined products. There has been a trend of declining waterborne shipments of petroleum products as a result of production shifting from Alaska to Canada and the Bakken region of the United States and a shift to rail transportation. The trend is expected to continue and then stabilize with a forecast of a negative 0.4 percent growth rate from 2013-2035 (BST Associates, 2014). This trend could be impacted by proposed oil transfer projects in Grays Harbor, Vancouver, Portland, and British Columbia. The potential impact of these proposed facilities to vessel transit is discussed below.

The Port of Grays Harbor is constantly in competition with other ports, not only nearby in the Puget Sound and Columbia River but also among the west, east, and gulf coasts. The port has previously been able to diversify as products being shipped have shifted away from forest products and towards other cargo like auto exports to maintain a competitive edge. However, the competition between ports is also based on rail rates, port rates, and ocean accessibility, so it is unknown how this will affect the port in the future (Taylor et al., 2015).

Oil shipping and facilities

Another dynamic factor in attempting to forecast cargo movements to and from PNW ports is the energy sector. Proposals to develop new or modify existing bulk crude oil terminals exist for two facilities on the coast of Washington as well as several others in Oregon, Washington, and British Columbia that could impact the coast. If they are permitted, such new facilities could increase the number and type of vessel transiting through the MSP study area and increase the volume of crude oil carried through the area.

One of the proposals is to expand existing bulk liquid storage facilities owned by Contanda (formerly Westway Terminal Company) at the Port of Grays Harbor. The maximum annual throughput of crude oil would be 17.9 million barrels per year (City of Hoquiam & Washington State Department of Ecology, 2016). A proposal by Imperium Renewables Inc. to expand existing bulk liquid storage facilities at the Port of Grays Harbor has been paused as new ownership under the name Renewable Energy Group (REG) reevaluates the expansion proposal. (Washington State Department of Ecology, n.d.).

Contanda operates at Terminal 1 at the Port of Grays Harbor and proposes to expand facilities to store crude oil brought in by rail from the Bakken area in the U.S. or from Canada. For the Contanda proposal, either tankers or tank barges could be used. If tank barges are used, it would result in an additional 119 annual vessel calls at Terminal 1 or an additional 238 vessel trips through the navigation channel when operating at maximum throughput (City of Hoquiam & Washington State Department of

Ecology, 2016). The final Environmental Impact Statement (EIS) was released for the Westway Expansion Project in September 2016 and Contanda (Westway) is waiting for a decision on the Shoreline Substantial Development Permit by the City of Hoquiam (Washington State Department of Ecology, n.d.).

Oil Spill Response

Vessels transiting the MSP Study Area bring the potential for oil spills, an ongoing challenge of managing marine transportation. There are a number of state and federal laws and regulations that address the potential for oil spills on or near the water and the associated preparedness and response planning and actions. The Washington State Department of Ecology (Ecology) has responsibility for preventing and planning for oil spills in state waters. Ecology is also responsible for organizing a rapid and coordinated response to oil and hazardous substance spills wherever they occur in the state.

Vessels transporting oil have a variety of required measures that contribute to the prevention of oil spills. The features include construction design (double bottoms and sides), mechanical measures (oil discharge monitoring systems and emergency shutdown devices), and navigational equipment (depth sounders and electronic position fixing devices to verify position and prevent collisions or groundings). Onsite storage and handling facilities at the terminal and trains that transport oil also have federal and state design standards, equipment, and training requirements to prevent oil and pollutants from reaching the environment. The Environmental Impact Statement (EIS) for the proposed Westway crude oil expansion recommends over 70 mitigation measures for the facility and project related vessels and trains. The proposed mitigation for vessel transport includes use of tug escorts for laden tankers and tank barges in Grays Harbor and implementing a formalized vessel management system. The EIS identified that no mitigation measures would completely eliminate the adverse consequences of a fire, spill or explosion and the potential adverse environmental impacts could be significant. (City of Hoquiam & Washington State Department of Ecology, 2016).

There is a coordinated oil spill response framework including the National Contingency Plan, Northwest Area Contingency Plan, local response plans, facility response plans, vessel response plans, and transportation regulations that establish roles and responsibilities, identify resources, and identify response procedures for oil spills or threat thereof. The Northwest Area Contingency Plan covers Washington, Oregon, and Idaho and includes site-specific geographic response plans (GRPs). A GRP has two main objectives: to identify sensitive resources at risk of injury from oil spills and to describe and prioritize strategies to protect these sensitive resources at risk. (City of Hoquiam & Washington State Department of Ecology, 2016). Relevant GRPs to the MSP Study Area include the Strait of Juan de Fuca, Outer Coast, Grays Harbor, Willapa Bay, and Lower Columbia River.

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2.8 Military Uses

The military has a prevalent historical and current presence within Washington State and the MSP Study Area. Primary ocean activities include the United States Department of the Navy training and testing ranges and the United States Coast Guard operations for navigation, search and rescue, vessel safety, and coastal defense.

Summary of History and Current Use

United States Department of the Navy

The United States Department of the Navy has had an active presence within the State of Washington since the mid-nineteenth century. Currently active range complexes within the Navy's Northwest Training and Testing Area include areas in Pacific Ocean offshore waters, Puget Sound, and Alaska. These sites have existed for decades. The Navy's mission is to maintain, train, and equip combat-ready naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas. This mission is achieved in part by conducting training and testing within the MSP Study Area (United States Department of the Navy, 2015).

Navy training and testing in the Pacific Northwest is conducted in established maritime operating areas and warning areas, including air and water space areas in the eastern North Pacific Ocean, which overlap with the MSP Study Area. These training and testing areas are located within and outside of Washington state waters. Existing range complexes and facilities that overlap with the MSP Study Area include the Northwest Training Range Complex and the Naval Undersea Warfare Center Division Keyport Range Complex (Map 40). The Northwest Training Range Complex (NWTRC) encompasses land, air, and sea areas that extend westward into the Pacific Ocean from the Strait of Juan de Fuca to 130 degrees west longitude (about 250 nautical miles), and southerly parallel to the coasts of Washington, Oregon, and Northern California. The Naval Undersea Warfare Center Division Keyport Range Complex includes the Quinault Range Site, which is located off the coast of Jefferson and Grays Harbor Counties and includes a 1 mile surf zone area at Pacific Beach, WA (United States Department of the Navy, 2015).

The Navy protects America's global interests around the world by operating on, above, and below the sea. In addition to keeping the sea lanes open to travel and trade, the Navy needs to be ready to respond to a wide range of situations such as large scale conflict, homeland defense, anti-piracy operations, and humanitarian assistance and disaster relief. This level of readiness and capability is achieved through comprehensive, realistic training and testing. The key to ensuring national security, maintain freedom of the seas, and avoiding tragic loss of life is to ensure that Sailors receive realistic training that fully prepares them to defend the United States, and that the equipment they rely on is thoroughly tested prior to use.

The Navy tests ships, aircraft, weapons, combat systems, and sensors and related equipment, and it conducts scientific research activities to achieve and maintain military readiness. The Navy performs training activities in the offshore area (MSP Study Area) such as anti-air warfare, anti-surface warfare, anti-submarine warfare, electronic warfare, mine warfare, and naval special warfare. Sonar, ordnance, munitions, and targets are used during Navy testing and training activities. Flight formation practice, submarine mine exercises, target practice, tracking exercises, and torpedo testing are some specific examples of the types activities the Navy performs (United States Department of the Navy, 2015).

United States Coast Guard

The United States Coast Guard and its preceding agencies have been operating in Washington State since 1854. The arrival of the cutter Jefferson Davis in 1854 and the construction of 16 lighthouses in Washington during the 1850's, including the Cape Disappointment Lighthouse, established the Coast Guard's presence in Washington (Washington State Department of Archaeology and Historic Preservation, 2011). Today, the U.S. Coast Guard 13th District serves Washington, along with Oregon, Montana, and Idaho, and is headquartered in Seattle.

The purpose of the Coast Guard is to safeguard the Nation's maritime interests in the heartland, in ports, at sea, and around the globe. The Coast Guard plays a vital role in navigational safety and regulation in the region. Coast Guard activities within the MSP Study Area include conducting search and rescue, patrolling the coast to enforce safety and fisheries regulations, conducting safety and compliance inspections and exams on commercial vessels and waterfront facilities, and protecting our nation's strategic defense and critical infrastructure. The Coast Guard also includes an Auxiliary, a civilian volunteer element of the Coast Guard which focuses on recreational boating safety (United States Coast Guard, 2015).

The U.S. Coast Guard serves the dangerous waters of the Washington Pacific coast. The stormy and foggy weather that frequents the MSP Study Area necessitated the development of several lighthouses and lifesaving stations to protect lives and respond during emergencies. Today, the 13th District operates within the Study area based out of units in Ilwaco (Station Cape Disappointment), Westport (Station Grays Harbor), La Push (Station Quillayute River), and Neah Bay (Station Neah Bay) (Map 40) (Washington State Department of Archaeology and Historic Preservation, 2011). The Coast Guard also operates and maintains several federal aids to navigation throughout the Study Area (United States Coast Guard, 2015). While some areas may be subject to higher activity based on proximity to units or other infrastructure, the Coast Guard operates throughout the entire MSP Study Area.

Related Infrastructure

Within the Study Area, the Navy's activities consists mostly of training and testing activities, and no pier-side infrastructure is located within the MSP Study Area (United States Department of the Navy, 2015). Infrastructure for the Coast Guard includes lifesaving stations, lighthouses, stations to house fleet operations, and federal aids to navigation. Coast Guard Units are operated out of Neah Bay, La Push, Westport, and Ilwaco. Federal aids to navigation, which include lighthouses, buoys, warning signs, sound signals, warning lights, and others are located throughout and adjacent to the Study Area (United States Coast Guard, 2015).

Future Trends

The Navy and the Coast Guard will continue to operate within the Study Area, with possible adjustments to their activities based on requirements to fulfill their respective missions. The Navy will continue to train and test within the Northwest Training and Testing Area, and has recently reassessed some activities starting in 2016. No changes in Navy range areas or new range sites are currently proposed (United States Department of the Navy, 2015).

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2.9 Research and Monitoring Activities

Marine waters off Washington's outer coast host a wide variety of research and monitoring activities conducted by numerous institutions and government agencies, many focused on baseline data to understand oceanographic conditions. Other research includes fisheries and other marine animal population surveys, habitat surveys, and tectonic research. Emergent issues such as hypoxia, ocean acidification, water temperature, and harmful algal blooms are already a focus of research and will likely continue to expand in the future.

Summary of History and Current Use

Washington's marine environment is the scene of a variety of oceanographic, geologic, and marine biology research. Several academic and research institutions, governments, and other organizations participate in research activities within the MSP Study Area. Examples of organizations conducting research and monitoring include the University of Washington School of Oceanography, Oregon State University, NOAA's Pacific Marine Environmental Laboratory, Northwest Fisheries Science Center, National Centers for Coastal Ocean Science, National Data Buoy Center, tribal governments, WA state agencies, and the Olympic Coast National Marine Sanctuary. Other federal agencies that perform research also include the United States Fish and Wildlife Service, United States Geological Survey, and the Olympic National Park. Many of these institutions work collaboratively with each other and others organizations through research centers and initiatives, such as the Northwest Association of Networked Ocean Observing Systems (NANOOS), the Ocean Observatories Initiative, and the Oregon Health Sciences University's Center for Coastal Margin Observation and Prediction (see NANOOS, 2015; Oregon State University, 2015; University of Washington, 2015).

A primary focus of research within the Study Area is collection of baseline data to understand oceanographic conditions, marine habitats and populations, and marine hazards. Data collected include temperature, salinity, carbon dioxide levels, tides, water currents, oxygen levels, and plankton blooms along with other oceanographic parameters (NANOOS, 2015). Population assessments for fishery resources, seabirds, and marine mammals are conducted routinely for management and conservation purposes (e.g., Menza et al., 2015; NOAA Fisheries, 2015). Other research is directed at, but not limited to, intertidal, pelagic, and deep-sea habitat (Office of National Marine Sanctuaries, 2008), the Cascadia Subduction Zone (e.g., Johnson, Solomon, Harris, Salmi, & Berg, 2014), benthic substrate sampling and seafloor habitat mapping (e.g., Goldfinger, Henkel, Romsos, Havron, & Black, 2014; Office of National Marine Sanctuaries, 2008), and coastal geomorphology.

Equipment for research includes research vessels outfitted with sampling and trawling gear, moorings, anchored hydrophones, shore-based instrumentation, and in-water gliders equipped with oceanographic sensors. Research vessels owned by state universities are based in Seattle or Newport, Oregon. NOAA's research ships serve the entire West Coast from California to Alaska, are based in Newport, Oregon. State agencies operate small (<30 feet) research vessels. Private vessels can also be contracted for specific projects. Research vessels, gliders, and other mobile equipment may perform established transect cruises, or focus on more temporary locations for specific projects. Fixed-location platforms may be deployed seasonally or year-round.

Related Infrastructure

Limited infrastructure is in place within the MSP Study Area to conduct long-term monitoring. Permanent and semi-permanent infrastructure includes buoys, moorings, and shore side stations (Map 41). These are generally equipped with sensors to measure oceanographic conditions, such as water temperature, carbon dioxide, light, wave height, wind, etc. Oceanographic buoys, both seasonal and year-round, include NANOOS' Chá bă buoy and accompanying NEMO sub-surface profiler off of La Push, NOAA NDBC's Cape Elizabeth and Neah Bay buoys, and the Olympic Coast National Marine Sanctuary's nearshore seasonal mooring array (NANOOS, 2015). Another example is the Washington Line, which is a part of the Ocean Observatories Initiative's Endurance Array and consists of three buoys transecting east-west recently deployed offshore of Grays Harbor (Woods Hole Oceanographic Institution, 2011).

Future Trends

Although not the most spatially extensive use within the MSP Study Area, research and monitoring activities will continue to have a presence within Washington's offshore and nearshore waters. The Study Area will likely remain an important area for scientific research and resource management surveys, particularly for understanding key processes and issues such as sustainable fisheries, ocean circulation, climate change, water temperatures, ocean acidification, hypoxia, fisheries populations, and harmful algal blooms.

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2.10.1 Marine Renewable Energy

Marine renewable energy is the conversion of potential energy from offshore wind[1], waves, and tidal currents to electric power through the installation of energy generating devices in the marine environment. The State of Washington, the United States, and several other countries around the world have identified marine renewable energy as a potential option to help diversify their energy portfolio and reduce carbon emissions from traditional energy sources, such as coal, oil, and gas (Copping et al., 2013; Musial & Ram, 2010). The State of Washington's Energy Independence Act of 2006, also known as Initiative 937, enacted a Renewable Energy Portfolio Standard that requires electricity utilities with 25,000 or more customers to acquire a minimum percentage of their power from eligible renewable energy resources.[2] Minimum percentage targets were set at 3% of total load from renewable energy by January, 2012, 9% by January 2016, and 15% by January 2020 (RCW 19.285).

The types of renewable energy that qualify under the Renewable Energy Portfolio Standard include marine renewable energy (i.e. offshore wind, wave, and tidal currents) and other renewable energy types such as terrestrial wind[3], solar, biomass, and biodiesel.[4] Solar, biomass, biodiesel, ocean thermal energy conversion, and other renewable energy resources are currently not relevant options within the MSP Study Area and therefore are not addressed here.

Marine renewable energy is a potential new use of ocean space within the MSP Study Area and state law requires marine renewable energy to be addressed within the MSP. Specific requirements include a series of maps that summarize locations with high potential for marine renewable energy production with minimal potential for conflicts with other existing uses or sensitive environments (RCW 43.372.040(6)(c)). Also required is a framework for coordinating state agency and local review of proposed energy projects (RCW 43.372.040(6)(f)).

The MSP is non-regulatory, meaning that it does not have the authority to explicitly approve or prohibit marine renewable energy projects. The MSP can identify key information about offshore wind, wave, and tidal current technologies, suitability, related infrastructure, environmental concerns, potential compatible uses, potential conflicts, and potential locations where energy generating facilities could be sited to reduce environmental and user conflicts. This information is used as context to inform MSP recommendations made by the State and shaped by stakeholders. The following sections within this chapter provide key information about marine renewable energy.

Summary of History and Current Use

History in United States and the World

Several countries around the world are currently promoting the use of marine renewable energy. Europe is currently the leader in offshore wind development and installed capacity, and has several testing sites for wave and tidal energy devices (Copping et al., 2013; Navigant Consulting, Inc., 2014;

[1] Offshore wind energy is wind energy extracted over water and is therefore included as marine renewable energy in the MSP.

[2] Utilities may use renewable energy credits or bundled renewable energy resources to meet the targets. Renewable energy resources must be located within the PNW, with limited exceptions.

[3] Terrestrial wind has been the predominant renewable resource acquired so far (Washington State Department of Commerce, 2014a).

[4] Most hydropower (i.e., energy derived from hydroelectric dams) is not included as an eligible renewable energy source to meet the Portfolio Standard (RCW 19.285).

Sotta, 2012). As of 2015, the currently installed global offshore wind energy capacity was about 12,107 megawatts (MW) (Global Wind Energy Council, 2015). Navigant Consulting (2014) estimated that about 6,600 MW are currently under construction globally, yet the future long-term capacity growth of the industry is uncertain. Several pilot projects have tested wave and tidal current energy technology and environmental effects around the world (Copping et al., 2013; Pacific Northwest National Laboratory, 2015). Wave and tidal current technologies are mostly in the pre-commercial (research, development, and testing) phase (Augustine et al., 2012), however the first commercial tidal current array became operational in Scotland in 2016 (Nova Innovation Ltd., 2016).

The United States has an active interest in marine renewable energy. The U.S. is working toward diversifying its energy portfolio, with a strong interest in advancing clean energy technologies. A diverse clean energy portfolio can increase the nation's energy security while reducing emissions that contribute to climate change (Musial & Ram, 2010). Offshore wind, wave, and tidal current energy resources, technologies, market factors, infrastructure requirements, cost feasibility, and other factors are being actively assessed by institutions such as the Department of Energy's National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratory, the Northwest National Marine Renewable Energy Center (NNMREC), Electric Power Research Institute (EPRI), and others (Augustine et al., 2012; EPRI, 2011; Lopez, Roberts, Heimiller, Blair, & Porro, 2012; Musial & Ram, 2010; Navigant Consulting, Inc., 2013b, 2014; Schwartz, Heimiller, Haymes, & Musial, 2010).

The first wind farm in the United States, Block Island Wind Farm, began operations in December 2016 off the coast of Rhode Island. A number of other offshore wind projects are in advanced stages of development across the country (Navigant Consulting, Inc., 2014). The Bureau of Ocean Energy Management (BOEM), the federal agency responsible for issuing leases for offshore energy in federal waters, has created several wind energy areas along Atlantic coast to facilitate development of projects. BOEM has awarded lease sales along the Atlantic coast through competitive auctions and is in the process of scoping and announcing additional lease sales. BOEM has also processed several unsolicited lease requests. BOEM task forces and panels have been established in at least 14 states to help coordinate between federal, state, and local governments and engage stakeholders (Navigant Consulting, Inc., 2014).

In Oregon, a proposed offshore wind project about 18 miles offshore from Coos Bay is currently in the permitting phase. The WindFloat Pacific Project is planned to consist of up to five deep-water turbines in approximately 350 meters (1,150 feet) water depth. Estimated project capacity is up to 30 MW. The project is scheduled to be commissioned in 2017 (Principle Power, Inc., 2013).

The U.S. also has a small number of wave and tidal current energy device testing facilities, sites, and pilot projects. that enable people to test the feasibility of technology as well as to study potential environmental effects (Augustine et al., 2012). The Pacific Marine Energy Center (PMEC) is an umbrella for marine energy testing facilities at NNMREC, a partnership between Oregon State University, the University of Washington, and University of Alaska Fairbanks. PMEC supports open-water testing of full-scale wave converters at the North Energy Test Site off Newport, OR (PMEC-NETS), sub-scale wave converters in Puget Sound, and river current turbines at the Tanana River Test Site near Fairbanks, AK (PMEC-TRTS). A grid-connected wave energy test site off Newport (PMEC-SETS) is also in the advanced stages of planning, and additional capacity to test sub-scale current turbines is being developed (Oregon State University, 2015). In addition to these facilities, the US Department of Energy and US Department of Defense have established the Wave Energy Test Site (WETS) on Oahu, HI for field testing of full-scale wave energy converters. Some pilot projects are anticipated to become larger scale commercial projects once testing is completed (PNNL, 2013).

Summary of History in Washington

The State of Washington saw several marine renewable energy proposals in the past, some located within the MSP Study Area. The MSP Study Area has significant offshore wind and wave resources (EPRI, 2011; Lopez et al., 2012; Schwartz et al., 2010), and limited tidal current resources (Van Cleve, Judd, Radil, Ahmann, & Geerlofs, 2013). However, there are currently no active operating or proposed marine renewable energy projects within the MSP Study Area.

A notable past energy proposal within the MSP Study Area was the Makah Bay Offshore Wave Energy Pilot Project. This project proposed four wave energy conversion buoys with an estimated 1 MW maximum capacity, enough to power about 150 homes on the Makah Indian Reservation. The project was estimated to have a mooring footprint of 625 x 450 feet and was to be located within the Olympic Coast National Marine Sanctuary (OCNMS). The project received a Federal Energy Regulatory Commission (FERC) conditioned license, which included approval of a 3.7 mile long transmission cable to connect to the onshore electricity grid. The Clallam County Public Utility District (PUD) planned to purchase the power once the applicant acquired all state and federal licenses (Federal Energy Regulatory Commission, 2006, 2007). The project proponent surrendered the rights to the project in April 2009, citing economic reasons (Federal Energy Regulatory Commission, 2009).

Another past proposal was for a tidal current energy demonstration project outside of the MSP Study Area in Puget Sound. Located in Admiralty Inlet near Whidbey Island, the Snohomish County Public Utility District #1 (SnoPUD) proposed installing two OpenHydro tidal energy turbines at a depth of about 190 feet to operate for three to five years. Starting in 2007, SnoPUD, along with other agencies and stakeholders, identified potential environmental impacts and performed several baseline studies collecting information such as physical environment, benthic habitat, and water quality data. SnoPUD received a FERC pilot project license in March, 2014 (PNNL, 2014). In September 2014, SnoPUD issued a press release stating that they suspended the tidal pilot project due to rising costs (Snohomish County Public Utility District No. 1, 2014) and they surrendered the FERC license in December 2015.

The University of Washington is a partner in NNMREC for researching and testing tidal current devices, and has supported testing for two intermediate-scale temporary wave converters, one in Puget Sound and one in Lake Washington; both outside of the MSP Study Area (Oregon State University, 2015). Further wave energy converter testing in Lake Washington is planned and NNMREC is also modifying a vessel to conduct in-water testing of research-scale current turbines, scheduled to begin testing in 2016 (B. Polagye, personal communication, June 7th, 2015). PNNL's Marine Laboratory in Sequim has also received funding for testing environmental monitoring technologies potentially in the presence of scaled tidal current or wave power devices (S. Geerlofs, personal communication, May 20th, 2015).

Current and Emerging Technologies

As mentioned above, marine renewable energy involves converting naturally-occurring energy in the ocean into electricity from three types of energy resources available within the MSP Study Area: offshore wind, wave, and tidal current. The following sections briefly describe the associated technologies for harnessing each of these three resource types.

Offshore wind energy

Offshore wind energy technology evolved directly from the land-based wind energy industry. Wind turbines operate by converting kinetic wind energy into electrical energy. Turbines typically have three blades and rotate around a hub which is connected to a nacelle with a gearbox and generator (Figure

2.10.1-1) (Augustine et al., 2012). Offshore wind turbines are trending toward larger sizes compared to onshore wind turbines because larger turbines can capture energy more efficiently and are not constrained by land-based transportation logistics which restrict onshore wind turbine size (Navigant Consulting, Inc., 2013b, 2014). U.S. planned offshore wind projects currently have an average turbine capacity of about 5 MW, ranging from 3 to 8 MW (Navigant Consulting, Inc., 2014). For example, the turbines for the planned WindFloat Pacific project have 6 MW capacity with rotor diameters up to about 500 feet (Principle Power, Inc., 2013). Some manufactures are pursuing turbine designs in the 10 to 15 MW range (Navigant Consulting, Inc., 2014).

The amount of power produced from an offshore wind farm will depend upon the installed capacity of the project, wind speeds, location, and capacity factor. The capacity factor is the percentage of time that the generator is producing power. The average capacity factor for recently installed offshore wind projects ranges from about 28%-50% (Navigant Consulting, Inc., 2014), which is greater than terrestrial wind with an average net capacity factor of about 32% in the Columbia Basin (Northwest Power and Conservation Council, 2016).

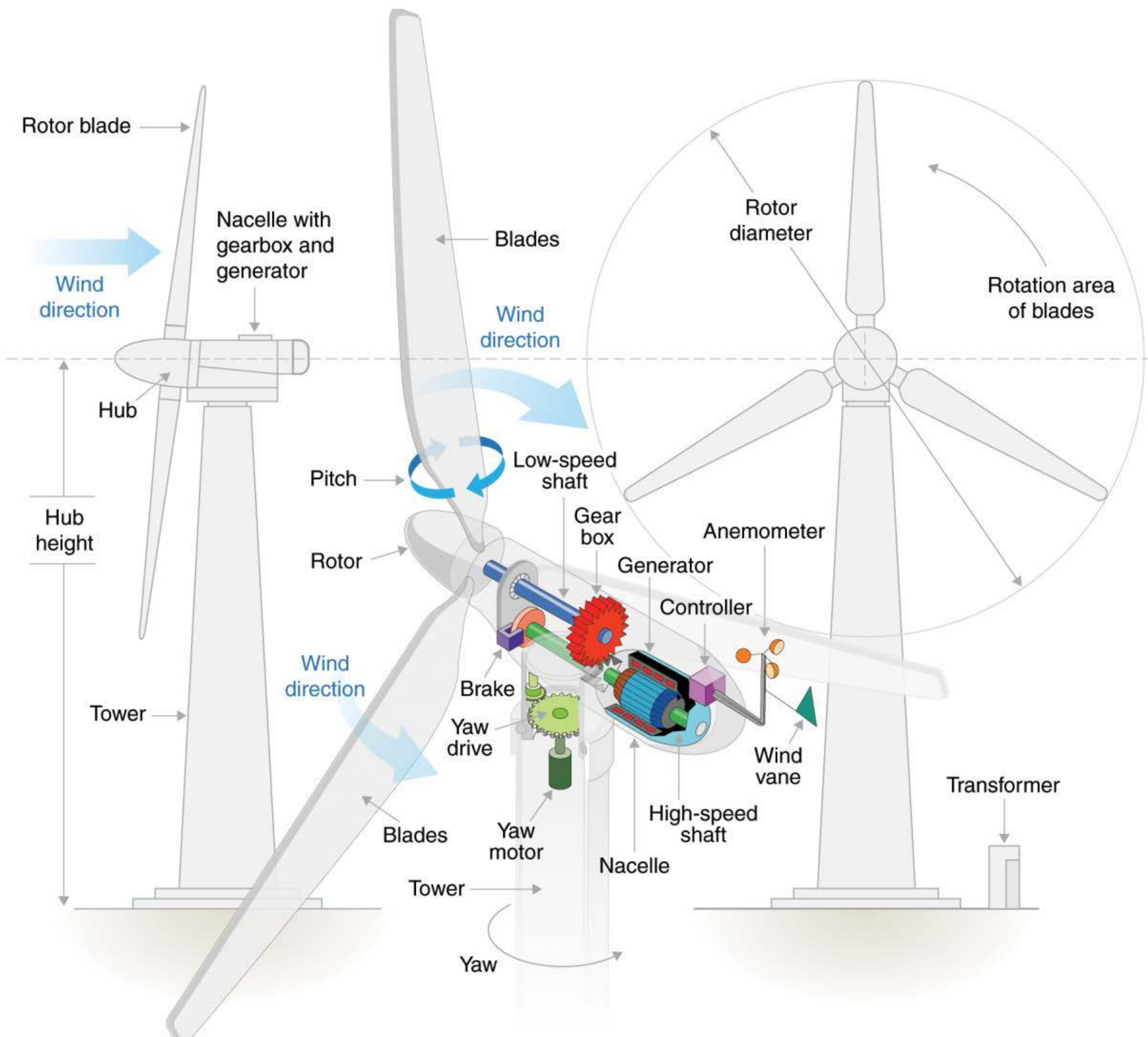

Figure 2.10.1-1. Components of a wind turbine. Source: Augustine (2012).

Offshore wind turbines are attached to foundations within the marine environment. These foundations vary in design, with different designs suitable for different water depth zones. The most commonly used foundation in currently constructed projects globally is the monopile design, followed by a gravity base design (Navigant Consulting, Inc., 2014). These two foundation designs are suitable for shallow water in about 30 meters (100 feet) or less (Musial & Ram, 2010; Sotta, 2012). Technologies under development and demonstration for transitional water depths (30 to 60 meters; or 100 to 200 feet) include tripod, jacket, multipile (Musial & Ram, 2010), and twisted jacket foundations (Department of Energy, 2014).

At greater than 60 meters depth (200 feet), bottom-fixed structures are no longer economically feasible and therefore require floating foundations that are moored to the bottom. These designs include floating semi-submersibles, tension leg, and spar buoy (Musial & Ram, 2010) (Figure 2.10.1-2). The anchor and mooring systems will vary by floating project. For example, the Coos Bay WindFloat project, which uses a floating semi-submersible design, is planning to use vertical load anchors commonly used in the oil and gas industry (Principle Power, Inc., 2013). Figure 2.10.1-3 shows the projected variations in offshore wind foundation designs by depth.

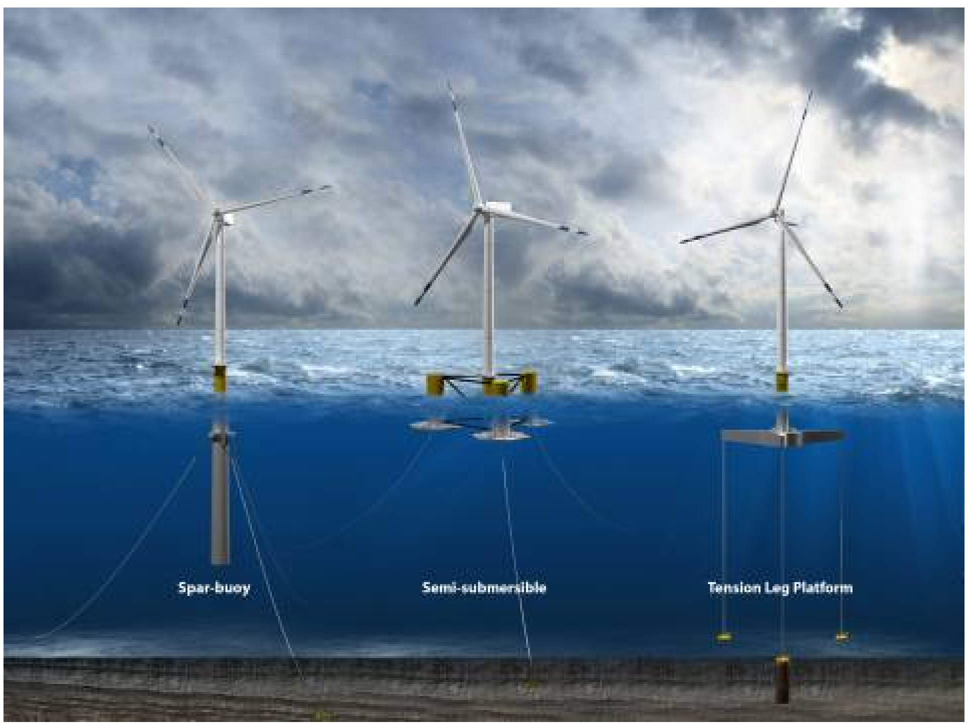

Figure 2.10.1-2. Offshore wind floating designs. Source: Department of Energy

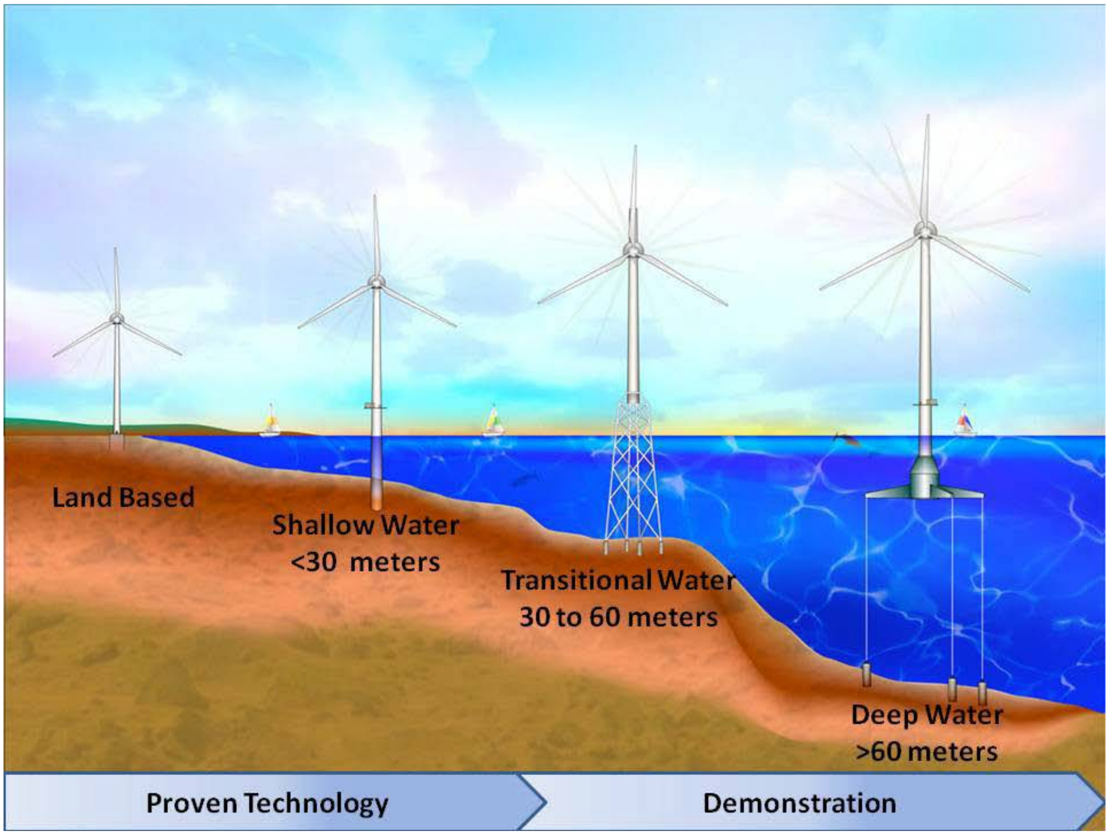

Figure 2.10.1-3. Diagram displaying example differences in offshore wind technology types by depth. Source: Musial and Ram (2010)

Wave energy

Wave energy is categorized as a type of marine hydrokinetic energy (MHK) technology. MHK technologies convert energy from a moving fluid, in this case a wave, into electricity (Augustine et al., 2012). Wave energy technology is in the early stages of development and is not as advanced as offshore wind. Many different wave technology designs are currently under development and testing in the U.S. and around the world (Augustine et al., 2012; Van Cleve et al., 2013). The following summaries describe some of the technology types for wave energy (2012). Figure 2.10.1-4 provides a visual of these technology types.

Point absorbers extract kinetic energy from the movement of a buoy relative to the ocean floor with the rise and fall of waves. This movement is converted to electrical energy either through a linear or rotary generator.

Overtopping devices allow waves to lift water over a barrier, which fills a reservoir that is drained through a hydro-turbine. They are often described as a low-head hydropower facility because they convert the potential energy of the elevated water in the upper reservoir to generate power much like a conventional hydropower dam.

Oscillating water columns are partially submerged structures. Air fills the upper part of the structure above the water level. Incoming waves are funneled into the structure from below the waterline, causing the water column within the structure to rise and fall with the wave motion. This alternately pressurizes and depressurizes the air column, pushing and pulling it through an air turbine mounted in a portal in the top of the column structure.

Attenuators capture wave-energy with a principal axis oriented parallel to the direction of the incoming wave. They convert the energy created by the relative motion of the articulated bodies of the device as the wave passes along it.

Inverted pendulum devices use the surge motion of waves to rotate a large, hinged paddle back and forth. The flapping motion drives hydraulic pumps that in turn drive electrical generators. Alternatively, linear generators are used to directly convert the wave energy into electrical energy.

An additional wave device type, the **M3 Nearshore Wave Energy Device** as described in the Pacific Northwest National Laboratory (PNNL) energy suitability analysis for Washington, is a pressure device that sits below the ocean surface and gathers energy from the pressure created in the sea column from passing waves (Van Cleve et al., 2013).

As described by Van Cleve et al. (2013), wave energy devices are designed for various depths, with some devices designed for the coastline and in shallow waters (<10 meters or 32 feet) with other designed for mid-water depths and water depths of up to 125 meters (410 feet).

Mooring technology and configurations will vary by project and technology type, and will be influenced by device array configurations and whether or not the project is motion-dependent (i.e., point absorber) or motion-independent (i.e., overtopping device) (Benjamins et al., 2014).

Tidal current energy

Tidal current energy is also categorized as a MHK technology by converting energy from a moving fluid into electricity[5]. Tidal turbines essentially work in the same manner as wind turbines, except they extract energy from flowing water instead of air. Similar to wave energy technology, tidal current energy technology is also in the early stages of development and has several different technology types and configurations (Augustine et al., 2012). Examples of tidal current technologies are shown in Figure 2.10.1-5. Tidal turbines require relatively strong currents to produce significant amounts of electricity. Depths of turbine deployment are dependent upon technology type and site factors. Tidal turbines sited below a commercial shipping lane will require at least 15 to 25 meters (49-82 feet) of overhead clearance and first-generation deployments have generally been outside of shipping channels (Polagye, Van Cleve, Copping, & Kirkendall, 2011).

[5] Tidal range technologies (also known as tidal barrages) are conventional hydropower in the marine environment and are not addressed within the Marine Spatial Plan.

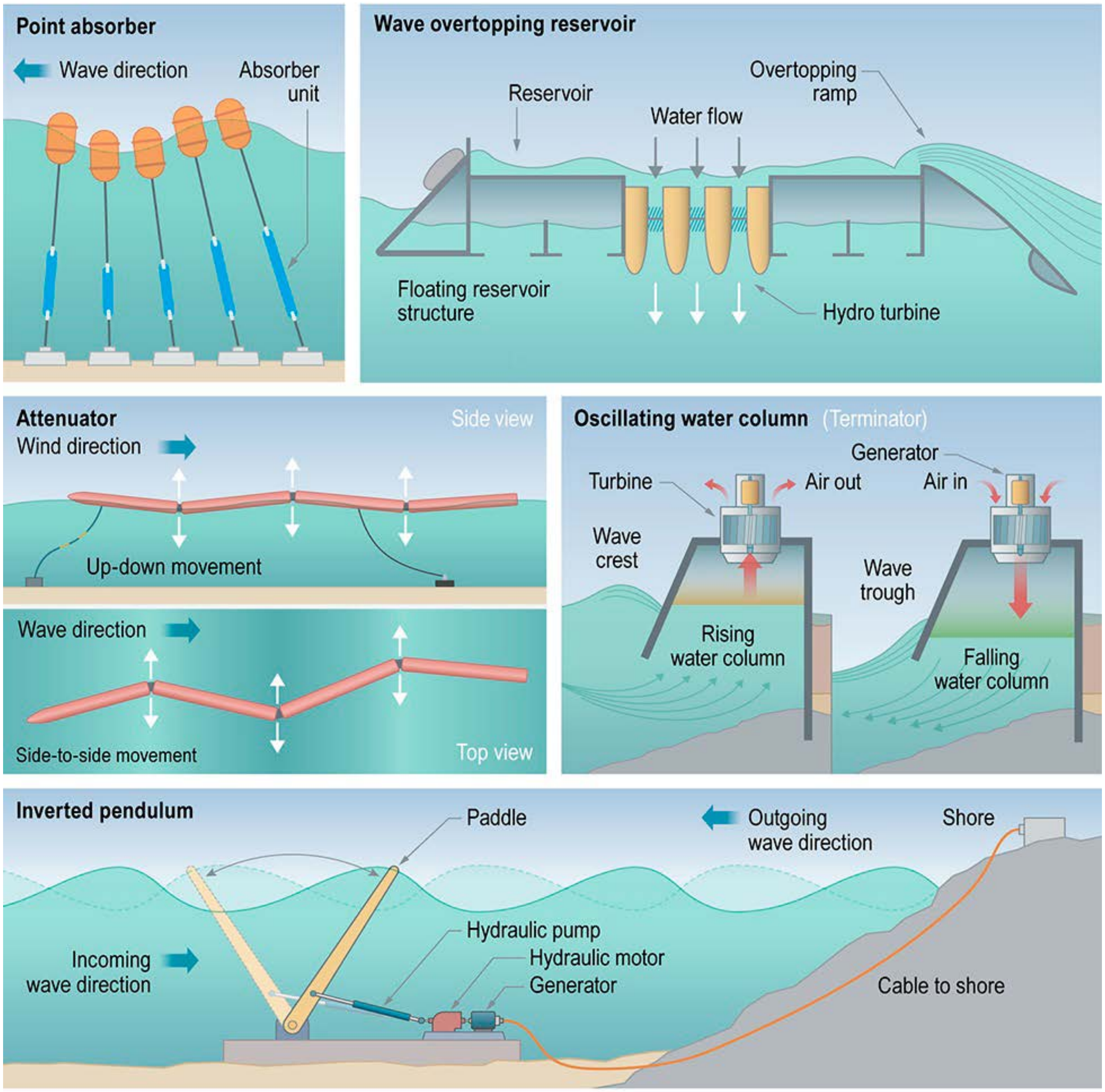

Figure 2.10.1-4. Wave energy technology types. Source: Augustine (2012).

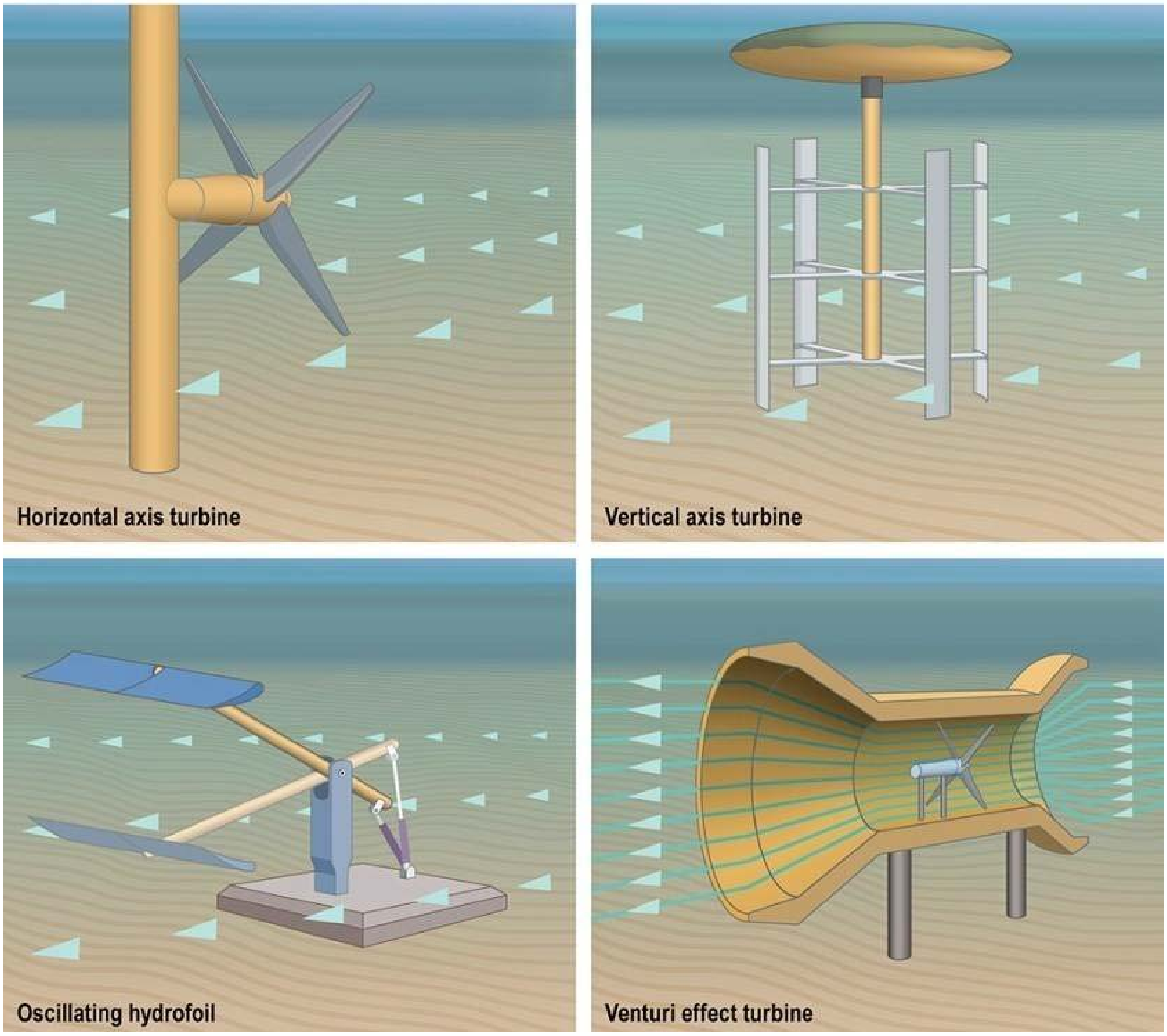

Figure 2.10.1-5. Primary technology types for tidal current energy devices. Source: Augustine (2012).

Related Infrastructure

Marine renewable energy will require energy transmission and support infrastructure. Energy transmission infrastructure will include cables from the device and submarine transmission cables to bring the energy to shore, along with shore-based substations to connect the energy to the electricity grid. Support infrastructure requirements will include ports, specialized service vessels, and likely coastal based manufacturing facilities (Musial & Ram, 2010).

Energy transmission infrastructure

The exact energy transmission infrastructure technology requirements will depend upon the specific energy project. Common elements of existing offshore wind energy infrastructure include inter-array electric power cables, transformer stations to collect the power and step-up the voltage, long-distance transmission cables, and onshore substations to connect the energy with the electricity grid (Navigant

Consulting, Inc., 2014). Wave and tidal device arrays will also have these basic components (Boehlert, McMurray, & Tortorici, 2008; Polagye et al., 2011).

Underwater power transmission cables are made up of a conductive material, such as copper or aluminum, and are surrounded by insulation (Bergstrom et al., 2012). Electricity flowing through the long-distance transmission cables is either Alternating Current (AC) or Direct Current (DC). Efforts to develop effective and efficient long-distance transmission technologies for both high voltage AC and DC are underway (Navigant Consulting, Inc., 2014). Transmission cables will either be buried or weighted along the seafloor depending upon sediment type and risk to the cable (Bergstrom et al., 2012). If the sediment type allows, cables can be buried from 1 to 3 meters (3 to 10 feet) deep to insulate and protect the cable (Polagye et al., 2011). When the cable approaches shore, Horizontal Directional Drilling (HDD) may be used to make landfall at an onshore substation by crossing under sensitive nearshore areas (Polagye et al., 2011).

Another important part of the energy transmission infrastructure is the availability of onshore substations and connections to the land transmission grid. The distance from marine renewable energy projects to land-based substations and the transmission grid will influence where energy projects can be feasibly sited (Van Cleve et al., 2013). These substations must also be capable of accepting additional electricity loads for distribution (electricity "on-ramps"), and therefore existing substations and transmission lines may need upgrades to accommodate added capacity (Industrial Economics, Inc., 2014).

Marine renewable energy developers continue to face challenges and complications to overcome transmission capacity and efficiency constraints for bringing the energy to shore and integrating it into the grid (Navigant Consulting, Inc., 2014). Some developers are exploring the option of providing non- or limited-grid connected, site-based energy for remote coastal communities or for powering other nearby uses such as aquaculture or desalinization. Examples include a wave buoy array that provides electricity to a military station on an island in Australia, where the energy is used to help power a desalination plant (Yee, 2015), and a company in Scotland testing wave energy to provide electricity to finfish farms (Mercador Media, 2014). The Makah Bay Offshore Wave Energy Pilot Project is a local example of interest in providing site-based energy for remote communities within the MSP Study Area.

Support infrastructure

Marine renewable energy projects will require various types of maritime support infrastructure for construction, operation, and decommissioning of devices. Distances to service ports, deepwater ports with sufficient overhead clearance (offshore wind), and helicopter operations (offshore wind) were identified by PNNL to be contributing attributes to suitable locations for marine renewable energy projects (Van Cleve et al., 2013). Specialized vessels will also likely be required (particularly for shallow water offshore wind) for installation, operation, maintenance, and decommissioning. Under the Jones Act, only U.S. flagged vessels are allowed to serve marine renewable energy projects (Musial & Ram, 2010).

Potential benefits and use compatibilities

Potential benefits of marine renewable energy

Marine renewable energy has the potential to provide many benefits to Washington's local coastal communities, the state, and the nation. Commonly cited benefits to marine renewable energy include providing a cleaner, renewable energy source to replace conventional carbon-emitting energy sources, providing opportunities for economic development, diversifying the energy portfolio, and increasing energy security.

Cleaner, renewable energy

Marine renewable energy is considered a clean energy source because it does not burn carbon rich fuel sources (a.k.a. fossil fuels) which, as a result, emit carbon into the atmosphere and contribute to climate change and ocean acidification (Boehlert et al., 2008; Musial & Ram, 2010; Polagye et al., 2011). Clean energy can displace the use of traditional, fossil fuel energy sources and thereby mitigate climate change and reduce the risk of catastrophic spills associated with fossil fuel extraction and transportation (Polagye et al., 2011). Marine renewable energy is considered “renewable” because it is continuously produced from the interactions of the sun-water cycle and geography, unlike depletable inputs of oil, natural, gas, or uranium. Offshore wind and wave energy are a form of solar energy, and tidal energy is a result of gravitational force between the earth, moon, and sun (Augustine et al., 2012).

Washington State has a history of producing and obtaining its electricity from renewable energy sources. In 2012, Washington produced about 84% of its total annual electricity consumption from renewable sources. Hydropower (dams) accounted for 77% of total electricity consumed, land-based wind accounted for 6%, and other renewable accounted for about 1% (Washington State Department of Commerce, 2014b). The Renewable Energy Portfolio Standard, enacted in 2006, is an example of Washington’s commitment to increase energy availability from clean, renewable energy sources. The Washington Department of Commerce administers a Clean Energy Fund for Washington research institutions to develop or demonstrate clean energy technologies (Industrial Economics, Inc., 2014).

Economic development

According to the U.S. Department of Energy, NREL, and the Navigant Consortium[6], offshore wind has the potential to significantly contribute to the U.S. domestic manufacturing sector and create high-paying, stable jobs (Musial & Ram, 2010; Navigant Consulting, Inc., 2013b, 2014). A domestic offshore wind industry is estimated to create direct jobs in manufacturing, installation and decommissioning, and maintenance and operations. These jobs can represent temporary and permanent positions.

At this time, it is difficult to estimate how many new jobs a marine renewable energy project in Washington will create because these numbers are based upon project-specific details, such as project size, project type, infrastructure update requirements, and others. Some of these jobs may be locally sourced, while others may be sourced throughout the region, state, country, or internationally. NREL estimates that most of the labor for the U.S. offshore wind industry will be sourced locally or regionally (Musial & Ram, 2010). It is possible that a marine renewable energy project may displace jobs from other industries (e.g., commercial fishing) due to direct space conflict and other factors (see Potential human use conflicts), causing further uncertainty related to the economic effects from marine renewable energy within the region. Once a specific project is proposed, it may be possible to perform a jobs cost-benefit analysis to provide a more accurate estimation of the type of economic effect a project may have on the local community and the State.

Washington has already gained economic benefit from the WindFloat Pacific project in Oregon from Washington based companies participating in the development, permitting, and siting of the project. In

[6] The Navigant Consortium is led by Navigant Consulting, Inc. Other members include the American Wind Energy Association, the Great Lakes Wind Collaborative, Green Giraffe Energy Bankers, National Renewable Energy Laboratory (NREL), Ocean & Coastal Consultants, and Tetra Tech EC, Inc. (Navigant Consulting, Inc., 2014).

addition, some Washington based companies are or will be suppliers of components for floating offshore wind installations (A. Weinstein, personal communication, May 15th, 2015).

Diverse energy portfolio and increased energy security

Another commonly cited benefit of marine renewable energy development is the diversification of the energy portfolio (Copping et al., 2013; Musial & Ram, 2010; Navigant Consulting, Inc., 2014). The U.S. is actively pursuing a broad suite of domestic energy developments, from expanding domestic oil and gas operations, to investing in both renewable and fossil fuel energy technology development (Department of Energy, 2012). A diverse energy portfolio will increase national energy security by reducing reliance on foreign energy sources (Department of Energy, 2012; Musial & Ram, 2010). NREL estimates that offshore wind has the potential to contribute significantly to the U.S. clean energy portfolio (Musial & Ram, 2010; Schwartz et al., 2010).

Marine renewable energy has the potential to provide energy near coastal demand centers (Musial & Ram, 2010). Transmission infrastructure updates would be required, and there is active interest on the Atlantic coast in developing a comprehensive offshore transmission plans for offshore wind projects (Navigant Consulting, Inc., 2014). Some rural Washington coastal communities have also recognized this potential benefit and are looking to increase their local energy supply. The majority of coastal communities, including tribal communities, are currently the end of the line for energy transmission and power supply from the grid can become unreliable during high demand periods (Industrial Economics, Inc., 2014). The former Makah Bay Offshore Wave Pilot Project planned to produce energy for up to 150 homes on the Makah Reservation (Federal Energy Regulatory Commission, 2006) to improve energy resilience. Some experts have indicated that small-scale community based projects continue to have some potential in the MSP Study Area in the near future (10 to 15 years) (Industrial Economics, Inc., 2014), yet the cost may be a limiting factor for the near term (A. Weinstein, personal communication, May 15th, 2015).

Potential compatible uses

Properly designed and sited marine renewable energy projects have the potential to be compatible in space and time with specific ocean uses. While there are few direct on-the-ground examples of compatible uses due to the limited deployment of marine renewable energy projects, a number of potentially compatible ocean uses have been identified. Examples of current uses that may be compatible include recreational fisheries, tourism activities, fishing exclusion zones, and some types of aquaculture. Opportunities for compatible uses will likely depend on project type (offshore wind, wave, or tidal), size, and other factors.

Boehlert et al. (2008) and Bergstrom et al. (2014) state that renewable energy projects are very likely to act as Fish Aggregation Devices (FADs). Recreational fisheries may benefit from targeting their efforts near a project site, as this type of activity and benefit has been reported around offshore oil and gas platforms in the Gulf of Mexico (Bureau of Ocean Energy Management, 2012b). This benefit may be influenced by potential exclusion zones around project sites.

Boehlert et al. (2008) and Bergstrom et al. (2014) discussed the possibility of marine renewable energy co-existing with fishing exclusion zones since a project may exclude some commercial and recreational fishing. The FAD effect combined with fishing exclusion may act as a fish protection area and possibly boost some fish populations. The potential for energy projects to be co-located with currently established and future fishing exclusion areas will be influenced by the goals of the fishing exclusion area and the ability of the energy project to meet those goals.

Tourists may be interested in viewing renewable energy projects, either from land or by boat, which could attract tourists to an area with an energy project. Studies reviewed in Musial and Ram (2010) found that some land-based and offshore wind projects have boosted the tourism industry within a project area. Shipping may also be compatible with offshore wind farms and tidal current energy arrays. Depending on the separation distance between wind turbines, it is possible that shipping lanes could be located within offshore wind sites (Industrial Economics, Inc., 2014). Tidal current devices may be sited below commercial shipping lanes, if there is an overhead clearance of 15 to 25 m (49-82 feet) (Polagye et al., 2011). Stakeholders also mentioned the possible benefit of improved search and rescue operations in ocean waters surrounding energy projects (Feb WCMAC meeting summary).

In regards to marine renewable energy compatibility with future uses of the ocean, Buck (2010) discussed the potential for co-location of offshore wind with offshore shellfish aquaculture. The foundation structures for offshore wind may provide an opportunity for anchoring, protecting, and accessing shellfish cultured in the ocean environment. Using marine renewable energy to provide electricity to aquaculture operations is also a prospect currently under development (Mercador Media, 2014).

Potential environmental impacts

Potential effects to the marine environment from marine renewable energy are a key concern to many scientists, regulators, and stakeholders, and the industry. While active research is working to study, monitor, and model potential environment effects from marine renewable energy deployments in ocean and coastal waters, relatively little is known about the level of actual impact that these devices may have when deployed at substantial scale (Bergstrom et al., 2014; Boehlert et al., 2008; Clark, Schroeder, & Baschek, 2014; Copping et al., 2013; Musial & Ram, 2010; Polagye et al., 2011; Sotta, 2012).

Multiple efforts around the world are establishing a scientific knowledge base about offshore wind, wave, and tidal current devices and their potential impacts to the marine environment. Among the most notable is the Tethys database hosted by PNNL which serves as a clearinghouse for information about offshore wind, wave, and tidal environmental research, literature reviews, and other data from around the world (Pacific Northwest National Laboratory, 2015). Annex IV, an international partnership connected with Tethys, produced a report with a series of case studies analyzing existing information about MHK (Copping et al., 2013). In 2016, Annex IV released a report on the state of the science about the environmental impacts of renewable energy as an update to the 2013 report (Copping et al., 2016). A variety of other reports from experts in the Pacific Northwest, United States, and other countries are also referenced here.

In general, these reports have identified and discussed numerous potential environmental effects and impacts, yet there is often relatively high uncertainty (i.e., a potential effect may actually be significant or may turn out to be inconsequential). Limited deployments of marine renewable energy projects, mostly at pilot and small-scales, make studying potential effects and increasing certainty difficult. Overall, the literature generally agrees that the majority of potential effects are of low concern for small-scale projects, and the impacts from multiple large-scale commercial operations, while possible, are uncertain (Bergstrom et al., 2014; Boehlert et al., 2008; Clark et al., 2014; Copping et al., 2013; Musial & Ram, 2010; Polagye et al., 2011).

The following sections review the primary potential effects discovered in the literature and are organized generally by impacting mechanism, also known as a stressor. The information review focused mainly on comprehensive summary reports accessed from the Tethys database. Many potential environmental effects identified are common among wind, wave, and tidal devices, while others are more technology specific. The following review presents potential effects generally for marine renewable energy and any predicted effects specific to a device are highlighted. Possible environmental effects, predicted level of impact, and uncertainty as discussed in the literature are described for each impacting mechanism when available.

Noise

Acoustic disturbance (a.k.a. noise) is a potential effect of marine renewable energy devices in the ocean and coastal environment. Noise can be generated from sources such as construction activities, machinery and moving parts (such as moving turbine blades or generators within wave buoys), wave and wind interactions, and strum noises from mooring cables (Bergstrom et al., 2014; Boehlert et al., 2008; Polagye et al., 2011). Noise from construction, particularly noise generated from pile driving, is the source of noise most commonly cited within the literature as having the largest potential for negative impact to marine animals. Pile driving creates intense, pulsed noise, has been observed to cause avoidance behavior in marine mammals, and is likely to cause mortality and tissue damage in fish (as cited in (Bergstrom et al., 2014; Sotta, 2012). Pile driving may be used for monopile and jacket foundation installations for offshore wind (relatively shallow water) (Bergstrom et al., 2014), and possibly tidal current devices, also depending on the water depth (Polagye et al., 2011).

Mitigation techniques presented in the literature to reduce harm to marine animals from construction sound include slow ramp-up for pile driving, bubble curtains, and acoustic deterrents (Polagye et al., 2011). Bergstrom et al. (2014) summarizes mitigation measures for construction activities including avoiding important recruitment areas for marine mammals and fish and timing construction activities outside of key migration time periods. New pile driving technologies have also been developed that inherently reduce noise generation without secondary mitigation measures (Reinhall & Dahl, 2011).

The operational sources of noise (machine operation, strum, wave and wind interactions, etc.) are expected to be low frequency and low intensity. Some marine animals may be sensitive to low frequency sounds, such as baleen whales (gray and humpback whales) and fish. It is possible that these low frequency sounds could either deter or attract whales, which could restrict migration corridors, reduce feeding areas, or increased susceptibility to predation by killer whales. Fish may experience behavior changes or loss of sensory capabilities. Fish thought to be particularly noise-sensitive include salmon, sardines, herring, rockfish, midshipman (*Porichthys* sp.), and a number of other groundfish species (Boehlert et al., 2008). Hearing thresholds and responses of whales, pinnipeds, and fish are uncertain (Copping et al., 2013).

Low frequency, continuous sounds may be masked by environmental background noise. Devices will likely be located in high energy areas subject to relatively high background noise (e.g., waves, rain, bubbles and spray, sediment movement) (Boehlert et al., 2008; Copping et al., 2013; Polagye et al., 2011). Isolating and measuring sound generation and propagation from marine renewable energy devices is difficult, particularly in high energy environments (Copping et al., 2013, 2016). Experts recommend that baseline studies of background noise, field observations, and sound modeling be used to determine the nature of the sound produced from marine renewable energy device arrays (Boehlert et al., 2008; Copping et al., 2016; Polagye et al., 2014, 2011).

Mitigation methods to reduce the effect of operation noise from wave energy devices presented in Boehlert et al. (2008) include varying the array design to reduce synchronous sound (additive noise), thicker mooring cables to reduce the frequency of cable strum, cable anti-strum devices, and developing wave technology with noise reduction designs.

Some marine animals may not be able to detect sound produced by renewable energy devices, or on the other hand, could even be attracted to the devices (Boehlert et al., 2008). Animals unable to hear the device arrays, animals that become confused as a result of multiple sound sources, or animals attracted to the devices may be at increased risk for collision and injury. The use of sound "pingers" has been considered as an acoustic deterrent method for marine mammals (Copping et al., 2013).

The Annex IV case study on acoustic disturbance of MHK devices summarizes field, laboratory, and modeling studies for determining noise effects and risk to marine animals. Based on this case study, Copping et al. (2013, 2016) conclude that the limited available information suggests that animals are unlikely to be killed or seriously injured as a result of noise disturbance from operation or construction activities. There is higher uncertainty around the behavior, hearing shifts, or migratory effects from noise disturbance. Copping et al. (2013, 2016) indicate it is unlikely that individual devices or small arrays will have large-scale effects on animal behavior or survival and most concerns are related to the uncertainty around additive noise from larger device arrays. More data will need to be collected as additional devices are deployed.

Entanglement

Entanglement of marine megafauna (whales, sharks, pinnipeds, and other large animals) in mooring lines of marine renewable energy devices is another commonly expressed environmental concern, yet there is little direct evidence to substantiate this concern (Benjamins et al., 2014; Boehlert et al., 2008; Industrial Economics, Inc., 2014; Polagye et al., 2011). Two recent literature searches performed by Benjamins et al. (2014) and Kropp (2013) concluded that marine renewable energy devices pose a relatively low to modest risk of entanglement to large marine animals.

Benjamins et al. (2014) assessed reports of entanglement for a wide variety of large marine animals encompassing fisheries and other marine activities throughout the world. They also reviewed marine renewable energy mooring system designs and created a qualitative risk assessment approach to assess relative risk to marine animal groups. The authors concluded that for most animal groups, entanglement in marine renewable energy moorings is not likely to pose a major threat. They did indicate that baleen whales may be at greatest risk due to their size and foraging habits. The authors also cautioned that relative risk may be influenced by mooring configuration, with catenary moorings having the greatest relative risk and taut moorings have the lowest risk (Benjamins et al., 2014).

Benjamins et al. (2014) also concluded that the large majority of entanglement reports to date are associated with ropes from fishing gear, with very few reports of large marine animals becoming entangled in moorings or cables of any kind. The authors stated that a greater risk posed by renewable energy device moorings may come from entanglement and bycatch in derelict fishing gear caught on moorings or energy devices, as this gear will continue to capture and likely kill animals.

A similar study by PNNL (Kropp, 2013) assessed entanglement risk to baleen whales, particularly gray whales, from potential wave energy parks along the U.S. West coast. Kropp (2013) assessed biological, behavioral, and migratory patterns of whales. The study described how whales become entangled in slack fishing lines, in which the slack in the fishing lines wraps around whale body parts. Kropp (2013) stated that moorings for wave energy devices would not have sufficient slack to entangle a whale. The study concluded that entanglement with wave energy device moorings in Oregon waters should not be a significant issue for baleen whales.

Electromagnetic Fields

Electromagnetic fields (EMF) can be produced by underwater energy transmission cables. The types of EMFs emitted include an electric field, an induced magnetic field, and induced electrical field created from the movement of water through the magnetic field. Cables can be shielded to prevent direct electric field emissions, but the induced magnetic and electric fields cannot be completely shielded. AC and DC underwater cables, therefore, will emit induced electric and magnetic fields. There is significant uncertainty around the strength of the EMF emissions from marine energy cables, which will likely vary between projects (Woodruff, Cullinan, Copping, & Marshall, 2013). The strength of the EMF field is related directly the intensity of the source current and attenuates with distance from the cable (Polagye et al., 2011; Sotta, 2012; Woodruff et al., 2013). EMF may also be emitted from in-water generating devices themselves as well as transformer substations (Boehlert et al., 2008; Polagye et al., 2011).

Scientists and regulators have identified concerns about EMF effects on marine animals, particularly for animals that use natural electric or magnetic fields to locate prey and mates, avoid predators, or orient for migration. Species known to use electro-reception include elasmobranchs (e.g. sharks and rays), lampreys, sturgeons, and decapod crustaceans (e.g. Dungeness crab). Species known to use natural magnetic fields include elasmobranchs (e.g. sharks and rays), bony fishes (e.g. salmon and tuna), marine mammals, mollusks, and arthropods (Boehlert et al., 2008; Woodruff et al., 2013).

PNNL (Schultz, Woodruff, Marshall, Pratt, & Roesijadi, 2010; Woodruff et al., 2013) conducted preliminary laboratory studies to assess what potential effects EMF may have on fishes and invertebrates. Studied species included Coho salmon, Dungeness crab, Atlantic halibut, and American lobster. Studies included testing for behavior modification, food and predator detection, and developmental delays. These studies found limited evidence for significant differences between exposed and control groups, yet many of the studies were inconclusive due to sample sizes and husbandry challenges (Schultz et al., 2010; Woodruff et al., 2013). A study in progress on the U.S. East coast is currently assessing potential EMF impacts from high voltage DC cables to elasmobranch and American lobster movement and migration (King et al., in progress). It is important to note that there are already many submarine cables in the ocean associated with land-based energy transmission, yet studying the biological effects of these cables is difficult and conclusions are highly speculative (Bergstrom et al., 2012; Normandeau Inc., Exponent Inc., Tricas, & Gill, 2011).

Overall, literature summaries, environmental effects workshops, and limited empirical evidence indicate that EMF may have a relatively low potential impact to species, with likely localized effects. However, there is a high level of uncertainty surrounding the sensitivity and response of many marine species to EMF (Bergstrom et al., 2014; Boehlert et al., 2008; Schultz et al., 2010; Woodruff et al., 2013). Mitigation measures discussed in the literature include shielding and burying the cables to reduce potential exposure (Boehlert et al., 2008). However, more recent reports contradict this suggestion because burial does not actually reduce the EMF, but only increases the distance between the species and the cable. This lowers the maximum EMF encountered in the water column, but for some species this may make the EMF more attractive (Copping et al., 2016).

Marine animal strikes

Offshore wind and tidal current energy devices operate with rotating blades. Stakeholders and regulators are concerned with the potential for marine animal strikes with turbine blades (or other similar moving parts). Species identified that may be at risk from interaction with tidal turbine blades include sea otters, pinnipeds (e.g. seals and sea lions), whales, sea turtles, fish, and diving birds (Copping et al., 2013). Birds and bats are also at risk from strikes with wind turbines (Flowers, Albertani, Harrison, Polagye, & Suryan, 2014).

An Annex IV case study (Copping et al., 2013) examined available information to estimate the effects of interactions between tidal turbine blades and marine animals. The case study included monitoring studies for potential marine mammal displacement at a tidal turbine site in Northern Ireland; fish interactions with tidal turbines in Maine, New York, and Scotland; fish survival after passing through a turbine in Minnesota; laboratory studies with fish; and mammal modeling encounters. Copping et al. (2013) concluded that the current limited information provides no evidence that direct interactions of marine mammals or fish with tidal turbine blades has caused harm to the animals, and results have not suggested that major effects should be expected as more devices are deployed. In the 2016 Annex IV update report, the authors again confirm no observed instances of marine mammals, fish, diving seabirds, or other marine mammals colliding with an operational tidal turbine (Copping et al., 2016). The authors do recommend that new technical methods need to be developed and implemented to observe the interactions of marine animals and turbines (Copping et al., 2016)

A study by PNNL assessing the potential and severity of an injury to a killer whale from a tidal turbine in Admiralty Inlet, Puget Sound suggested that strike risk was low, and the worst-case strike injury results would possibly be equivalent to bruising, although the injury data were limited and associated with high uncertainty (Carlson et al., 2014). Diving birds may be attracted to prey congregating around tidal turbines and therefore may be at risk of tidal turbine strike, but there is not much evidence to determine the level of risk (Copping et al., 2013; Sotta, 2012).

Offshore wind turbines may pose a risk to flying birds and bats. Information from bird strike risk mostly comes from land-based wind farms, where the impact of bird strikes is largely site specific. Studies suggest that birds are at higher risk of strike from wind turbines during storms, at night, or during other periods of low visibility (Musial & Ram, 2010; Sotta, 2012). Bird flight height and diving behavior also likely influences strike risk (Flowers et al., 2014; Musial & Ram, 2010; Sotta, 2012). Monitoring and modeling studies of European and commissioned U.S. offshore wind sites indicate a relatively low impact to birds from turbine strikes. Some monitoring studies in Europe suggest that many birds avoid flying through offshore wind farms and the collision rates are low (Flowers et al., 2014; Musial & Ram, 2010; Sotta, 2012). Birds strikes with wave energy devices, while possible, are considered by Sotta (2012) to be less likely than strikes with offshore wind turbines.

Limited information is available to assess the impact to birds from wind farm lighting. According to Musial and Ram (2010), no studies have documented negative impacts to birds from wind farm lighting. The authors do reference the behavioral attraction of nocturnal birds to offshore oil and gas platform lights, which suggests there may be an increased risk of strike to nocturnal birds. Wave energy workshop participants identified a strike risk to birds from lighting on wave energy devices as a potential high impact (Boehlert et al., 2008).

Bird strike risk reduction and mitigation measures highlighted by Musial and Ram (2010) include monitoring and understanding transient and resident bird behaviors, siting in areas that avoid high-density and migratory waterfowl areas, breeding areas, and migratory pathways of concern, and careful siting to avoid potential cumulative impacts.

Bat strikes with offshore wind turbines are also a concern, as this has been an issue with land-based wind turbines. There is limited information regarding bats and offshore wind farms, but it is known that bats do migrate over water. A monitoring study in Scandinavia suggested that bats did not avoid turbines when hunting for insects (Musial & Ram, 2010). Flowers et al. (2014) are currently developing a remote monitoring system to detect bird and bat interactions with offshore wind turbines.

Effects on biological environment

Marine renewable energy devices and associated moorings will create novel static structures within the marine environment. The presence of new structures can create a reefing effect, otherwise known as a fish aggregation device (FAD), where fish opportunistically congregate around these devices. FADs can be considered to have either a positive or negative effect on marine communities, depending on fish management goals and trophic interactions that occur as a result of the FAD. Some fish populations may increase, as the physical structure provides physical refuge and food from biofouling organisms. Other fish may experience increased susceptibility to predation, as predators may opportunistically target areas with high concentrations of prey. Predators could include fish, sharks, mammals, and seabirds (Bergstrom et al., 2014; Boehlert et al., 2008; Copping et al., 2013; Polagye et al., 2011; Sotta, 2012).

Overall, there is high agreement within the literature that marine energy devices will act as FADs, yet there is significant uncertainty surrounding what the exact interactions and influences this may have on individual species and the community (Boehlert et al., 2008; Copping et al., 2013; Polagye et al., 2011; Sotta, 2012).

As mentioned above, marine renewable energy devices and associated hard structures will also be subject to biofouling. Biofouling can increase populations of a variety of organisms, including mussels, sponges, kelp and other algae, and other sessile organisms. These organisms can provide food for fish and other predators. However, it is possible that these devices can provide habitat for non-native and invasive species colonization (Boehlert et al., 2008; Musial & Ram, 2010; Sotta, 2012). Invasive species have been documented on offshore wind turbines in Denmark and Sweden (as cited in (Musial & Ram, 2010).

Physical presence of marine energy device arrays may also influence migration patterns of marine species, including fish, mammals, and birds. Energy devices could create a physical barrier to migration, act as deterrent for animals actively avoiding the arrays, or could possibly attract some animals along their migration route thereby altering migration behavior. There is a significant level of uncertainty around this potential impact. Recommendations include avoiding major migratory routes when siting marine energy installations (Boehlert et al., 2008; Copping et al., 2013; Polagye et al., 2011).

Anchors, cables, and fixed foundations may directly disturb bottom habitat through placement and removal of the equipment. This effect was not discussed in detail within the literature, and in general effects were predicted to be low and localized (Boehlert et al., 2008; Polagye et al., 2011).

Effects on physical environment

Marine renewable energy devices are designed to extract energy from the marine environment, and the resulting decreased energy could influence physical processes. The physical presence of these devices could also affect physical processes such as wave propagation and water flow. Limited research is available on the impacts of marine renewable energy devices on the physical environment, and most concerns are highly speculative and restricted to large-scale deployments (Clark et al., 2014; Copping et al., 2013).

Concerns identified in the Annex IV case study (wave and tidal energy) include alterations to sediment transport and deposition, changes in tidal ranges and flushing rates of oxygenated seawater in enclosed waterbodies, changes in water movement that effect distribution of planktonic larvae or marine plant propagules, and changes in water column mixing. The authors noted that many of these potential effects would likely only occur when device arrays extract very large amounts of energy from the system (Copping et al., 2013). The majority of physical effects from single and pilot scale device deployments will likely be immeasurable, and measuring effects, even from large-scale deployments may be difficult, given natural variability. Effects might not be seen for years or decades after deployment, and can be difficult to distinguish from natural variations in conditions. Copping et al. (2013) highlight that baseline measurements of oceanographic conditions in high energy environments (the environments most suitable for energy devices) is limited due to challenges of deploying equipment. Modeling may be the best tool for understanding potential oceanographic effects from large-scale energy deployments, but current challenges exist for model validation (Copping et al., 2013).

Summary reports suggest that commercial-scale tidal current arrays in particular may influence water quality when placed in estuaries. These effects will likely be highly site specific. Modeling techniques for estimated energy changes are limited and there is much uncertainty surrounding the magnitude of impact to water quality (e.g., dissolved oxygen, temperature, salinity, water exchange, etc.) and habitat (Copping et al., 2013; Polagye et al., 2011).

Authors conducting a comprehensive review of research and modeling of offshore wind farms in the Baltic and North Seas came to similar conclusions for offshore wind effects on the physical environment (Clark et al., 2014). This study identified many similar physical effect concerns (wave propagation, water column mixing, sediment transport, etc.), and some additional wind related concerns. For example, offshore wind farms will produce a wind wake, but is it unclear to what affect this may have on the physical environment (i.e. wave propagation, given that wave generation occurs over large areas). Clark et al. (2014) stated that impacts are uncertain (especially for large offshore wind farms), the current accuracy of modeling is limited, and that most research indicates that any effects are either undetectable or remain within the footprint of the offshore wind farm.

Washington stakeholders specifically raised concerns about changes in wave action and sediment transport (February WCMAC Meeting summary). Current monitoring of offshore wind farms in Europe suggest that effects on wave action and sediment transport are generally localized and limited to the footprint of the offshore wind farm. Models of far-field (long distance) wave action and sediment transport effects from offshore wind farms vary in their results, with predictions ranging from no effect to reductions in beach width. The authors highlight that the disagreement between studies emphasizes that effects are poorly understood (Clark et al., 2014). The Annex IV case study for MHK devices also highlighted several modeling studies with highly variable results, generally influenced by energy device type and size of project array. The larger the array, the more potential for effects on wave action and sediment transport. However, current models are associated with high levels of uncertainty and directly measuring these effects will be difficult (Copping et al., 2013), particularly given the natural variability in coastal processes associated with storm events.

Chemical contaminants

Exposure to chemicals from marine renewable energy devices and operations is discussed in the literature as a potential concern. Polagye et al. (2011) divides possible chemical contaminants into two categories: fuel and hydraulic fluid spills from accidents and collisions, and slow release of anti-fouling chemicals into the environment. Hydraulic fluid leaks from devices are considered to be unlikely due to precautionary measures to contain fluids in the event of a leak during operation or maintenance, and therefore are considered to be of low concern (Musial & Ram, 2010; Polagye et al., 2011). Large oil spills from collisions (i.e. supply vessels, etc.) would likely have a high impact on fish, birds, habitats, and marine mammals, yet precautionary safety and response measures should limit the likelihood and extent of a large spill (Polagye et al., 2011).

Anti-biofouling chemicals may be continuously released into the marine environment. The effects will be dependent upon the specific chemicals used, and therefore the local and community effects are highly uncertain. Avoiding and minimizing the use of toxic anti-fouling chemicals (e.g., employing non-toxic foul release coatings) is recommended where feasible (Polagye et al., 2011).

Another factor related to chemical exposure is the possibility of chemicals becoming released into the water column from project placement or cable trenching over contaminated sediments. The potential effect is highly site specific and depends upon the contaminants present in the sediment. Avoiding contaminated sites for project and cable locations is recommended to avoid this potential impact (Polagye et al., 2011).

Potential impacts on human uses

Marine renewable energy has the potential to conflict with current and future uses of the ocean, thereby potentially impacting marine industries, local communities, and the state. Some of these conflicts are spatial in nature, meaning that the physical presence and use of ocean and coastal space will directly conflict with other uses.

Spatial conflicts

Spatial conflicts include interactions for usage of space. This can either be direct conflicts in space that may result in temporary or permanent displacement, increases in time or cost to complete an activity, or impacts that result from visual presence within a viewshed. Spatial conflicts may directly impact the economics of the affected industry, which could lead to hardships within the industries and the local communities which depend upon these activities. The MSP can be used to address spatial conflicts by considering these conflicts and identifying areas of high and low conflict to avoid and minimize impacts.

Direct displacement of fishing, shipping, and other activities

Marine renewable energy device arrays will take up physical ocean space. The amount of space needed for arrays will depend upon project specific factors such as device type, number of devices, array configuration, and mooring designs. The physical placement of these devices may displace current ocean uses, most notably fishing and shipping activities (Industrial Economics, Inc., 2014). The extent of displacement impact will depend upon project size and location. Offshore wind and wave device arrays placed within established shipping lanes could pose a direct safety conflict. Marine renewable energy devices could be sited to avoid shipping lanes, or lanes could be adjusted around project locations. Some stakeholders have indicated that depending upon spacing between offshore wind turbines, it is possible that shipping and other navigation uses could operate between the turbines (Industrial Economics, Inc., 2014). However, floating offshore wind installations would likely not be able to allow commercial shipping in between turbines due to the larger ocean floor footprint from moorings (A. Weinstein, personal communication, May 15th, 2015). Shipping and tidal current energy could potentially be compatible, if the turbines had at least 15 to 25 meters (49-82 feet) of overhead clearance within a shipping lane (Polagye et al., 2011).

Marine renewable energy projects may also directly conflict with commercial and recreational fishing activities (Industrial Economics, Inc., 2012). According to Bergstrom (2014), fisheries are not routinely excluded from offshore wind farms in Europe, but movements may be restricted for safety reasons. In the U.S., the first offshore wind farm, Block Island Wind Farm off the coast of Rhode Island, started commercial operations in December 2016. The U.S. Coast Guard established a 500-yard safety zone around each of the wind-turbine foundations while they were being constructed. Now that construction is completed the restrictions have been lifted and boats are free to transit as close to the turbines as they wish. The U.S. Coast Guard is the agency responsible for setting safety exclusion zones if necessary in the future at Block Island or at other offshore wind farms.

Particular fisheries, possibly due to gear type differences, may be subject to more displacement/exclusion than others. Impacts to various fisheries may also vary due to the nature of the fishery (highly localized versus a mobile pelagic fishery) and the type of displacement they experience. Navigation conflicts may include increased transit times to fishing grounds and possibly increased risk of collisions with device support vessels. Transmission cables may also pose a conflict with fisheries, particularly those fisheries which use bottom-contact gear equipment (Industrial Economics, Inc., 2012).

It is impossible to know at this point to what extent the impact to Washington fisheries would be, as this will be highly dependent upon project specifics, such as location, project size, mooring configuration, and device type. Spatial conflicts with fisheries may result in decreased catch, increased transit times and fuel consumption, and loss of gear. This could put economic stress on the industry, and may result in reductions in fishing jobs, decreases in jobs that rely on the fishing industry (seafood processors, maritime support, etc.), and impacts to the broader community.

BOEM has developed best management practices (BMPs) and avoidance and mitigation measures to foster compatible uses within offshore wind energy areas and decrease conflicts with fishermen. Several best management practices have been developed for the U.S. East coast (Ecology and Environment, Inc., 2014). These include a recommendation for a fisheries communication and outreach plan for communicating between the fishing industry and the project developer. Another recommended BMP is the use of siting considerations to avoid conflict by meeting with local fishing groups to avoid key fishing locations and seasons, maximize fishing access, communicate construction schedules, and discuss cable routing. Safety standards are another BMP, and would include recommendations for marking, radio, lighting, etc. as well as procedures for emergency events. An environmental monitoring BMP includes monitoring procedures and incident reporting requirements. The final recommendation is the consideration of financial assistance to mitigate hardships to fishermen and support continued fishing. Possibilities for monetary support may include financial assistance with gear improvements, port facility updates (e.g., freezers, storage facilities, etc.), fuel subsidies, or enhancing fisheries research (Ecology and Environment, Inc., 2014).

A study of several U.S. ocean regions (including the Pacific Northwest), which identified numerous potential conflicts and avoidance and mitigation measures upon which BOEM's BMPs were based, suggested that each local region may desire a tailored set of BMPs and mitigation measures to meet local circumstances. The report identified that commercial fishing stakeholders in the Pacific Northwest strongly preferred conflict avoidance over mitigation, and emphasized the fishermen's desire to be involved in the decision making process (Industrial Economics, Inc., 2012).

Other current ocean uses that may potentially conflict with marine renewable energy over direct use of ocean space include recreational activities, research activities, military operations, dredge disposal, archaeological and historical sites, and permanent infrastructure. Recreational boating may need to alter travel and destination patterns and there may be an increased risk to safety. Wave energy technologies which utilize surf waves may directly conflict with established surfing locations. Research activities with repeated sampling transects may also be affected if an energy array is placed along or near transects. Presence of marine renewable energy devices may alter data and disrupt long term baseline monitoring and scientific surveys (Industrial Economics, Inc., 2012).

Marine renewable energy devices may also pose a direct space conflict if sited within military practice zones and other frequently used military areas. Other designated areas, including dredge disposal zones and navigation channels, may also experience direct conflict if energy devices are located within or along frequently trafficked areas associated with these zones. Areas with permanent infrastructure, such as seafloor cables, may also be affected by marine renewable energy projects (Industrial Economics, Inc., 2012).

Potential direct spatial conflicts with historic, cultural, and archaeological sites are possible if projects are located on or directly near such sites (Industrial Economics, Inc., 2012). Construction, foundations, and moorings may damage historic resources. BOEM and other federal agencies are required under Section 106 of the National Historic Preservation Act to identify and assess impacts to historical resources. BOEM's regulations in 30 CFR 585, specifically regarding renewable energy leases on the outer continental shelf, require a site assessment to identify historic properties. State Historic Preservation Office consultations will also be required if the project occurs in state waters.

A space use conflict assessment funded by BOEM identified several potential avoidance and mitigation measures for a variety of uses, including many discussed above. The primary strategies identified for avoiding and mitigating conflict that could apply generally to several user-group conflicts included: spatial conflict avoidance through avoiding high use and high values areas, communication and stakeholder engagement to identify specific conflicts and avoidance/mitigation strategies, coastal and marine spatial planning, spatial analysis to understand areas of high economic and environmental value, and minimizing impacts through project design and construction. Environmental assessments, mitigation funds and subsidies, stock enhancements, research, emergency response plans, and other strategies were also presented (Industrial Economics, Inc., 2012).

Viewshed and tourism conflicts

Marine renewable energy projects may have varying degrees of visual impact along coastal or ocean viewsheds. How visible a project is will depend on the type of device (which influences the height and size of an array), distance from shore or other highly used ocean areas, and visibility of an area (i.e., fog and haze vs. a clear day). Due to the height and size of wind turbines, offshore wind will likely have the greatest potential impact on a viewshed, followed by wave energy. Within offshore wind structures, floating offshore wind will have the most flexibility to reduce viewshed impacts, as it can be sited farthest from shore. Tidal current energy may have little potential impact on a viewshed because the majority or entirety of the device will be located below the sea surface, with the exception of possible surface platforms or foundations.

Viewshed impacts are difficult to estimate. Local residents, tourists, and individuals from marine industries may have different perspectives and tolerances for viewshed alteration by marine renewable energy devices. Communities in Washington (February WCMAC meeting summary), the U.S. East coast, and Europe have expressed concerns related to the potential impact to tourism as a result of an altered viewshed. Evidence to date suggests that offshore wind farms in Europe have had little to no negative impact on tourism, and some European communities saw increases in tourism as people travelled to see operating offshore turbines (as cited in (Musial & Ram, 2010). Studies from Europe also suggest that individuals may become accustomed to the view change over time, exhibiting less resistance to a project once it became operational. The ultimate effects of marine renewable energy projects on tourism will likely be highly site specific and therefore potential impacts are associated with a significant amount of uncertainty (Musial & Ram, 2010).

Another concern related to viewshed is the potential impact on property values. No studies were available on offshore wind impacts to property values. U.S. based studies cited in Musial and Ram (2010) on land-based wind farms revealed that properties located within the viewshed of a wind farm had comparable property values to similar properties outside the viewshed. It remains unclear what effect offshore wind farms or other marine energy projects may have on U.S. coastal property values (Musial & Ram, 2010).

In addition, particularly pristine or culturally important viewsheds may experience more of an impact from the visual presence of marine renewable energy (Musial & Ram, 2010). Onshore substations and other new or expanded shore-side support infrastructure may also contribute to an altered coastal viewshed.

Use conflicts from physical effects

While marine renewable energy devices may directly conflict in space with many ocean uses, there is also the potential for conflicts with users that rely upon ocean energy resources, such as waves for surfers, wind for sailing activities, and coastal zone mixing for water quality. As described within the "Effects on the physical environment" section, energy devices work by extracting energy from the environment, which can reduce the energy within the system. Offshore wind turbines may create a wind wake, which may alter the leeward wind dynamics from an offshore wind farm (Clark et al., 2014). This may impact sailing activities, with likely more impacts the larger the offshore wind array (the more wind energy extraction), although these effects are uncertain. Offshore wind foundations and wave energy devices may also remove energy from waves, which could influence wave behavior (wave height, direction, etc.) (Boehlert et al., 2008; Clark et al., 2014; Copping et al., 2013) and potentially affect surf for surfing and other wave related user activities (Industrial Economics, Inc., 2012).

Energy extraction may also influence the surf mixing zone, tidal ranges, oxygen exchange, and water exchange. If these processes were altered, there may be affects to water quality and habitat along the nearshore, particularly for commercial-scale tidal current energy within semi-enclosed water bodies (i.e., estuaries) (Boehlert et al., 2008; Copping et al., 2013; Polagye et al., 2011). This could potentially impact coastal aquaculture and recreational shellfishing, which rely on natural physical processes to maintain water quality and optimal shellfish growing conditions, although it is currently unclear how likely or to what extent the impacts would be.

Impacts on water circulation, water quality, wave alterations, and other physical processes are highly uncertain (Clark et al., 2014; Copping et al., 2013; Polagye et al., 2011), and therefore so are the potential impacts to current uses that rely upon physical ocean processes. As mentioned earlier, small-scale and pilot projects in general are anticipated to have no measurable impact on physical processes, and high uncertainty surrounds the potential physical impact of large-scale commercial operations. Models may provide the best opportunity to predict the potential level of impacts (Clark et al., 2014; Copping et al., 2013; Polagye et al., 2011).

Potential conflicts with future uses

Marine renewable energy devices may also conflict with potential future and expanded ocean uses. In particular, conflicts may exist between future sand and gravel mining operations, new dredge disposal locations (Industrial Economics, Inc., 2012), and possibly some types of offshore aquaculture (i.e., current technology for finfish aquaculture). It is unknown at this time what the likelihood of these potential conflicts would be.

Permitting marine renewable energy

Marine renewable energy projects require a number of authorizations including licenses, leases, permits, and consultations. These actions are performed by several federal, state, and local agencies, often in coordination. This is a complex process that varies depending on the type of proposed project (offshore wind, tidal, or wave) and location (state, federal, tribal, or marine sanctuary waters). Agencies are working on refining the complex process and interagency interactions for marine renewable energy projects. The following describes the primary federal authorities for authorizing marine renewable energy projects in ocean waters.

Bureau of Ocean and Energy Management (BOEM)

BOEM has the authority to issue leases, easements, and rights of way for all renewable energy development (including offshore wind, wave, and tidal) on the Outer Continental Shelf (OCS). The OCS lies between the State's jurisdiction (3 nautical miles) and the Economic Exclusive Zone (200 nautical miles). BOEM has a flexible process for establishing leases for renewable energy which generally occurs in four phases: planning and analysis, leasing, site assessment, construction and operations (Bureau of Ocean Energy Management, 2014).

The Outer Continental Shelf Renewable Energy Program does not give BOEM the authority to issue a lease within the National Marine Sanctuary System (30 CFR 585.204). However, this does not necessarily mean that marine renewable energy projects cannot occur within the OCS of the Olympic Coast National Marine Sanctuary. Other federal agencies, such as the Federal Energy Regulatory Commission (FERC) and U.S. Army Corps of Engineers (Corps), are able to issue authorizations for marine renewable energy projects in Sanctuary waters.

BOEM can be the National Environmental Policy Act (NEPA) lead agency for preparing Environmental Impact Statements/Environmental Assessments for proposed projects on the OCS (40 CFR Parts 1500-1508; (FERC and U.S. Department of Interior, 2009). This means that, on the OCS, outside of the Marine Sanctuary, BOEM is the lead agency for evaluating and coordinating environmental review to ensure that the lease will not significantly affect the environment. BOEM coordinates with several federal, state, and local authorities, as well as the public, throughout the NEPA process. The NEPA process is completed prior to authorizing any lease, easement, or right of way. BOEM and FERC have agreed to cooperate on the NEPA process for wave and tidal energy projects within the OCS (FERC and U.S. Department of Interior, 2009).

Federal Energy Regulatory Commission (FERC)

FERC is an independent federal agency that regulates the interstate transmission of electricity, natural gas, and oil. FERC is responsible for licensing the construction and operation of hydrokinetic projects (wave and tidal) in state and federal waters. Some types of projects may conduct limited testing without obtaining a FERC license (Federal Power Act, 18 CFR Parts 4 and 5). FERC does not have authority over offshore wind power projects. FERC does have the authority to issue licenses for wave and tidal projects within Marine Sanctuaries (Bureau of Ocean Energy Management, 2012a).

FERC is the NEPA lead agency for wave and tidal projects in State waters (0 to 3 nautical miles), and wave and tidal projects within Marine Sanctuaries. FERC and BOEM have an agreement to work together in the NEPA process for wave and tidal projects within the OCS. Environmental analysis during the license phase of the project may be led by FERC with BOEM as a cooperating agency or with FERC and BOEM as co-leads. The two agencies have agreed that FERC will not issue a license in the OCS until BOEM has issued a lease to the applicant (FERC and U.S. Department of Interior, 2009).

U.S. Army Corps of Engineers (Corps)

The Corps is responsible for issuing permits under Section 10 of the Rivers and Harbors Act for any construction that will affect the navigable capacity of any waters of the United States. This includes wind, wave, and tidal projects in state and federal OCS waters. It is possible that a project authorized by FERC may not require a Section 10 permit from the Corps (Federal Power Act, 33 CFR Part 221.1(f)(1)).

Under Section 10 authority, the Corps is likely the NEPA lead agency for marine renewable energy projects that do not fall under BOEM or FERC federal authority. An example of this may be any offshore wind projects that are proposed within State waters, or possibly any offshore wind projects proposed within the Marine Sanctuary (since BOEM does not have the authority to offer leases within Marine Sanctuaries, and FERC does not have authority for wind projects). Federal agencies do have the option to choose which agency is the NEPA lead (40 CFR Parts 1500-1508). Therefore it is possible that another federal agency may take the lead when BOEM or FERC does not have authority.

The Corps is also responsible for issuing permits under Section 404 of the Clean Water Act for dredge and fill actions in any waters of the United States. This approval may be required to install marine renewable energy structures or devices in the marine environment.

Marine Renewable Energy Technical Suitability within the Plan Study Area

To support the MSP, PNNL produced a 2013 report, which analyzed potential technical suitability of various offshore wind, wave, and tidal current energy devices within the MSP Study Area. The report included a series of maps, as required by RCW 43.372.040(6)(c), which indicated the relative technical suitability of devices by location[7]. PNNL created these maps by evaluating site suitability using several criteria[8], which were grouped into three categories: site quality, shore-side support, and grid connection. The analysis evaluated potential technical suitability only[9], and did not take into account potential conflicts and considerations with current ocean uses (Van Cleve et al., 2013).

This section presents the maps and key results in the PNNL report for technical suitability of marine renewable energy with Plan waters. For further details on the analysis methods, results, and maps, please see the original report by Van Cleve et al. (2013).

Offshore wind energy suitability

Offshore wind energy assessments suggest that Washington has significant wind resources (Lopez et al., 2012; Schwartz et al., 2010). Van Cleve et al. (2013) assessed technical suitability for three offshore wind technology types: monopile (nearshore), tripod and jacket (mid-depth), and floating platform (deepwater). Three maps illustrating potential relative suitable locations for tripod and jacket, monopile, and floating foundation technologies are shown in Maps 42, 43, and 44 respectively.

In general, the southern half of the Study Area shows relatively higher areas of suitability than the northern half for all offshore wind foundation types. Areas offshore of Grays Harbor and Cape Disappointment show higher suitability for all three types of offshore wind, and floating offshore wind also shows higher suitability around Cape Flattery (Van Cleve et al., 2013).

Wave energy suitability

A report by EPRI (2011) estimates that Washington has significant wave resources. Wave energy technical suitability in the MSP Study Area was analyzed by Van Cleve et al. (2013) in four device groups: nearshore, nearshore M3, mid-depth, and deepwater wave. Maps 45, 46, 47, and 48 show the potential suitable locations for deepwater, mid-depth, nearshore, and nearshore M3 wave devices, respectively.

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[7] The suitability score was calculated using attribute scores and weighted models divided by a potential maximum suitability score. The maps summarize relative suitability based on these scores.

[8] Specific criteria analyzed were energy resource potential, depth, substrate, distance to substation, distance to shore, distance to transmission line, distance to service port/airport, and distance to deepwater port.

[9] Technical suitability was based off on input from the current marine renewable energy industry. Suitability may change as technologies mature.

Similar to site suitability patterns for offshore wind, all wave device groups displayed the highest relative suitability locations mostly in the southern half of the Study Area, particularly offshore from Grays Harbor and Cape Disappointment. High suitability areas were also located offshore from Cape Flattery (Van Cleve et al., 2013).

Tidal current energy suitability

Tidal current energy suitability is limited within the MSP Study Area. The suitability assessment combined all tidal current energy device types to create one tidal energy site suitability map, shown in Map 49. Van Cleve et al. (2013) identified one area at the Mouth of the Columbia River as having the potential for medium to low percent suitability for tidal current energy. All other areas showed no suitability. Van Cleve et al. (2013) did state that in the future potential sites may be discovered in Grays Harbor and Willapa Bay, particularly with new technologies optimized for lower current speeds.

Key results for suitability

PNNL assessed relative technical suitability for marine renewable energy sites based on economic and site feasibility factors; it did not assess suitability based on conflicts with current uses or ecological habitats. Suitability in this analysis is relative, meaning that a site with high suitability may not necessarily be an appropriate site. However, this analysis provides a valuable first look at what areas may be possible based on technical factors. The suitability results show a greater number of areas with higher suitability for renewable energy development in the southern half of the Washington coast than the northern half and many sites are suitable for more than one device type (Maps 42-49). Van Cleve et al. (2013) indicate that the primary driver of this pattern for offshore wind and wave technologies is grid connectivity, i.e. the lack of supporting electrical infrastructure, including transmission lines and substations along the northern mid-section of the coast (Map 50). The authors note that distance to shore support (service ports and deepwater ports) also influences this pattern and that areas most suitable for marine renewable energy development are within 25 miles of the coast. Tidal current energy has limited suitability within the MSP Study Area primarily due to lack of sufficient tidal flows for analyzed devices (Van Cleve et al., 2013).

Future Trends and Factors for Marine Renewable Energy

Several drivers and barriers exist for the marine renewable energy industry in Washington State. Significant offshore wind and wave energy resources exist within the MSP Study Area (EPRI, 2011; Lopez et al., 2012; Schwartz et al., 2010), and many areas have high potential technical suitability for wind and wave energy devices (Van Cleve et al., 2013), which could contribute to satisfying Washington State's Renewable Energy Portfolio Standard. Marine renewable energy projects may also stimulate economic development and provide high-paying, stable jobs (Musial & Ram, 2010; Navigant Consulting, Inc., 2013b, 2014).

However, the marine renewable energy industry is relatively new, and there are several economic, technological, and logistical barriers to its development (Augustine et al., 2012; Navigant Consulting, Inc., 2014; Van Cleve et al., 2013). Regional and locally specific factors, along with community concerns and high use of Washington's ocean space, add to the barriers for local development of marine renewable energy projects. A sector analysis (Industrial Economics, Inc., 2014) produced specifically for the MSP concluded that the likelihood of marine renewable energy development is limited over the next 20 years. There are currently no marine renewable energy projects operating or under development within the MSP Study Area.

Potential within the MSP Study Area

The technical suitability study by PNNL (Van Cleve et al., 2013) and the sector analysis by Industrial Economics, Inc. (2014) provide valuable information specific to the MSP Study Area. As discussed earlier in this chapter, PNNL's suitability analysis revealed a greater number of areas with higher suitability for marine renewable energy development in the southern half of the Study Area compared to the northern half. The primary driver of this pattern is the lack of grid infrastructure and distance to ports along the northern mid-section of the coast (Van Cleve et al., 2013). The presence of the Olympic Coast National Marine Sanctuary (OCNMS) along the northern half of the coast also lowers the likelihood for marine renewable energy projects (Industrial Economics, Inc., 2014), particularly for commercial-scale developments. However, marine renewable energy projects that are owned by a tribe could possibly be permitted within the OCNMS (15 CFR Part 922).

While the southern half of the MSP Study Area may be more technically suitable for marine renewable energy development (support and grid infrastructure), this area is also subject to heavy ocean use from marine industries including shipping and non-tribal fisheries. This may be a significant limiting factor for marine renewable energy development in the southern half of the MSP Study Area.

Experts have expressed mixed views with regards to commercial and small-scale projects. Some experts feel that small-scale, community based projects may be possible within the MSP Study Area, particularly for tribal or other local communities looking to increase their energy reliability (Industrial Economics, Inc., 2014). However, technology challenges and current high energy costs associated with small-scale projects limit the economic feasibility of local community projects. While commercial-scale projects may reduce the cost of energy, other factors such as limited experience in the U.S., significant initial investments in grid infrastructure and support infrastructure, conflicts with users, and other market factors limit the commercial-scale potential along Washington's Pacific coast over the next 20 years (Industrial Economics, Inc., 2014).

Of the marine renewable energy resources discussed, offshore wind was reported by Industrial Economics, Inc. (2014) to have the highest likelihood for development within the MSP Study Area over the next 20 years. The primary reason for this assessment was the advanced offshore wind technology, relative to wave and tidal current devices. Locations near Grays Harbor, a deepwater port, may be particularly favorable for offshore wind (Industrial Economics, Inc., 2014). Floating offshore wind is possibly the most likely technology type (A. Weinstein, personal communication, May 15th, 2015). Despite the abundant offshore wind resource, areas with potentially high technical suitability, and relative advanced stages of offshore wind technology development, Industrial Economics, Inc. (2014) reported that offshore wind development is still likely limited along Washington's Pacific coast over the next 20 years.

Past project proposals for small-scale community wave projects as well as the wave device testing sites in Oregon exemplify the interest in wave technology within the Pacific Northwest. However, given that the technology is still in its infancy, it is highly unlikely that commercial-scale wave energy projects will be developed within the next 20 years (Industrial Economics, Inc., 2014), with more possibility for small-scale projects, especially for remote communities.

Tidal current energy has limited technical suitability within the MSP Study Area (Van Cleve et al., 2013) and the technology is still quite new. Therefore, tidal energy development in the MSP Study Area is highly unlikely within the next 20 years (Industrial Economics, Inc., 2014).

Key Barriers

Cost

Cost has been identified as a primary barrier to marine renewable energy development in Washington, the U.S., and around the world (Industrial Economics, Inc., 2014; Navigant Consulting, Inc., 2014). Stakeholders are also concerned about how these projects will influence the cost of energy to consumers. In Washington, offshore wind, wave, and tidal current energy are currently not cost competitive with other sources of energy (Industrial Economics, Inc., 2014; Musial & Ram, 2010; Renewable Northwest, 2007). The Pacific Northwest currently has relatively low electricity prices due to abundance of hydropower dams in the region (Musial & Ram, 2010). In 2013, Washington had the lowest residential electricity prices in the nation (U.S. Energy Information Administration, 2014).

Many factors influence the life-cycle costs of marine renewable energy such as initial and operating costs, and cost of capital. (Musial & Ram, 2010; SI Ocean, 2013). Operation and maintenance costs also represent a significant portion of cost due to the logistics of operating in the marine environment (SI Ocean, 2013). Other factors that influence the cost of energy include the price of conventional energy (particularly natural gas), demand for power (i.e., increased demand from decommissioning coal power), and competition with industries that use similar resources (offshore oil and gas construction and manufacturing) (Navigant Consulting, Inc., 2014).

Significant investments in technology, transmission infrastructure, and other development factors are needed within the marine renewable energy sector. Investment risk is also relatively high, due to the novelty of the industry. Marine renewable energy currently requires incentives to be competitive with other energy sources, as many utility districts will likely be unwilling to pay higher premium prices. Costs are expected to decrease over time as technology advances and experience is gained (Augustine et al., 2012; Industrial Economics, Inc., 2014; Navigant Consulting, Inc., 2013a, 2014).

Ultimately, the cost competiveness (or current lack thereof) is the primary challenge to U.S. offshore wind development. U.S. federal and state incentive programs, such as research development grants and renewable portfolio standards, are currently needed to stimulate the industry (Navigant Consulting, Inc., 2014). Some stakeholders are concerned about possible energy price increases due to marine renewable energy development, and are skeptical of investing public dollars for initial investments and accepting risk with perceived limited local benefit. Local PUDs may be unwilling to pay the premium prices associated with marine renewable energy development in the near term (Industrial Economics, Inc., 2014).

Infrastructure requirements

Support and transmission infrastructure requirements to support marine renewable energy are another major barrier (Musial & Ram, 2010; Navigant Consulting, Inc., 2014), particularly for rural coastal Washington (Industrial Economics, Inc., 2014). All device types (offshore wind, wave, and tidal) will require existing onshore substations to be updated and adapted to serve as “on-ramps” for energy integration into the grid (Industrial Economics, Inc., 2014). Current integration of land-based wind indicates that integration of marine renewable resources is possible.

Support infrastructure will be required to install and service marine renewable energy projects and these requirements will depend on technology type. Offshore wind requires deepwater ports (channels deeper than 30 feet) (Van Cleve et al., 2013), as well as large assembly areas, and sufficient offloading equipment[10] (Musial & Ram, 2010). Washington currently does not have existing facilities to support offshore wind, yet there are potential locations where infrastructure could be updated (Industrial Economics, Inc., 2014). Navigant Consulting, Inc. (2014) suggests that public investment in port

[10] Construction and equipment requirements will vary between offshore wind foundation technology types.

infrastructure could significantly support offshore wind development, benefit other water transportation industries, and decrease long-term costs of renewable energy.

Marine renewable energy will require integration into the electricity grid. It is a variable resource, energy generation is not constant throughout time, which creates challenges for integration into the grid. The Northwest electricity industry[11] has adapted its grid infrastructure to be able to integrate approximately 11,500 MWs of land-based wind resources as of 2015 (Northwest PowerPool, 2015), which indicates the capability to integrate marine renewable energy resources, particularly in light of greater capacity factors observed for offshore wind than for terrestrial wind (Navigant Consulting, Inc., 2014; Northwest Power and Conservation Council, 2010).

The majority of the Washington coast is relatively rural and may not be able to absorb additional quantities of new offshore generated electricity through existing infrastructure, therefore updates to transmission infrastructure will be required to connect energy generated in the ocean into local PUDs and the larger transmission grid[12] (Industrial Economics, Inc., 2014). This will add to the initial costs of marine renewable energy development and will ultimately be reflected in the electricity rate (Navigant Consulting, Inc., 2013a). Some stakeholders may be skeptical as to whether the investment into these updates will benefit the local communities and are concerned about the ability of offshore transmission technology and grid connections to be successful and efficient.

Regulatory uncertainty

Regulatory uncertainty is a primary barrier for marine renewable energy development in the U.S. (Navigant Consulting, Inc., 2014). Multiple agencies are involved in the complex permitting process, and the timeframe, specific authorities and requirements, siting process, and other conditions are continuously being adjusted as agencies learn about this new ocean use. This creates a lengthy, costly, and uncertain process for developers. BOEM is currently working to improve their outer continental shelf leasing process (Bureau of Ocean Energy Management, 2014), and several agencies have entered into formal agreements with each other to outline authorities, responsibilities, and cooperation protocols (i.e. (Bureau of Ocean Energy Management, 2012a; Federal Energy Regulatory Commission & State of Washington, 2009; FERC and U.S. Department of Interior, 2009). As more projects are proposed and permitted, the regulatory process will likely improve. Also, the MSP may serve to reduce some uncertainty by providing a framework for permit coordination.

Conflicts with current uses

Spatial conflict with current ocean uses is another barrier to marine renewable energy in Washington. As described in the section "Potential human use conflicts", marine renewable energy may directly conflict with several key marine industries, such as fishing, recreation, and shipping (Industrial Economics, Inc., 2012, 2014), which are frequent and important users of the Washington coast (Section 2.4, Section 2.6, and Section 2.7 respectively). This may lead to economic stress and significant impacts to these industries and the surrounding communities. The potential impacts of displaced ocean space to these current uses may strongly influence development. Recommendations within the MSP are based on information about conflicts with ocean users. These recommendations may influence the location, extent, and process for marine renewable energy development. It is a goal of this Marine Spatial Plan to

[11] The Northwest electricity industry includes organization such as BPA, Puget Sound Energy, and other major local, state, and regional utility organizations.

[12] Transmission updates are often necessary for the incorporation of land-based wind energy as well, and have been performed with the expansion of this industry.

protect existing sustainable uses while encouraging economic opportunities that recognize the aspirations of coastal communities.

Environmental concerns

As described in the "Potential environmental impacts" section, there are many possible yet uncertain effects to the marine environment from marine renewable energy projects. This uncertainty may affect public perception and influence regulatory review of proposed projects, such as increased likelihood for additional environmental studies and monitoring requirements. There are also unknown mitigation requirements and uncertainties around the effectiveness of mitigation measures. Environmental uncertainty can increase cost and time for developers and increase resistance from stakeholders and environmental regulatory agencies. Environmental research at field test sites, in laboratories, and through models are filling in the many data gaps, yet many unknowns will remain until full-scale projects are deployed and monitored for several years (Bergstrom et al., 2014; Boehlert et al., 2008; Copping et al., 2013; Navigant Consulting, Inc., 2014; Polagye et al., 2011).

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RCW 43.372 Marine Waters Planning and Management

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Renewable Energy and Alternate Use of Existing Facilities on the Outer Continental Shelf 30 CFR 585.204

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2.10.2 Offshore Aquaculture

A potential new use of Washington's Pacific coastal waters is offshore aquaculture. Aquaculture, the culture or growing of fish, shellfish, or other aquatic plants and animals, has been a part of Washington's landscape for thousands of years. Current aquaculture activities are important sources of food and livelihood for many Washingtonians, including native peoples.

No aquaculture activities are currently taking place outside of the estuaries on Washington's Pacific coast. The potential expansion of aquaculture activities into ocean waters beyond the estuaries becomes increasingly possible due to technological advancements. The expansion of aquaculture into deeper, offshore waters is driven by the ever increasing demand for high quality protein and the limited space and suitability of coastal waters (Lovatelli, Aguilar-Manjarrez, & Soto, 2013; Rubino, 2008). Whether there is a future for offshore aquaculture will depend upon several factors, including feasibility of locations, technological advancements, economic potential, and compatibility with existing uses.

Summary of history and current use

Offshore aquaculture

There are many different ways to define offshore aquaculture. Some definitions use specific depth, distance, and exposure ranges (Lovatelli et al., 2013), while others use jurisdictional boundaries (e.g. federal waters). For the purposes of the MSP, the term 'offshore aquaculture' will be used to describe any new aquaculture operation within the designated Study Area yet outside of the coastal estuaries. Regardless of distance from shore, the exposure of Washington's Pacific coast to waves, storms, swells, and currents would pose the challenges and require the technologies consistent with offshore aquaculture.

Coastal aquaculture

Coastal aquaculture is highly prevalent in Washington. Coastal aquaculture along Washington's Pacific coast can be defined as aquaculture within estuaries, including Willapa Bay and Grays Harbor. As a state, Washington is ranked first by the U.S. Department of Agriculture in sales of aquaculture products. Coastal aquaculture on Washington's Pacific Coast consists mainly of Pacific oysters (*Crassostrea gigas*) and Manila clams (*Venerupis philippinarum*) (Industrial Economics Inc., 2014). These shellfish are cultured using methods such as bottom culture, longlines, flip bags, and racks. For more information about coastal aquaculture operations on Washington's Pacific coast, please see Section 2.5 Aquaculture in this report as well as the Aquaculture Sector Analysis (Industrial Economics Inc., 2014) and Economic Analysis report (Taylor, Baker, Waters, Wegge, & Wellman, 2015).

Coastal aquaculture, in general, has many economic and logistical advantages over offshore aquaculture, including limited exposure to storms, continuous access for operations, and close proximity to facilities (processing, storage, etc.) (Lovatelli et al., 2013). However, the potential for higher water quality and more space for larger operations at offshore sites make offshore aquaculture a future opportunity for the aquaculture industry (Knapp, 2013).

Current and emerging offshore technologies

Offshore aquaculture is still in its infancy. Operations around the world currently employ a limited number of technologies and techniques at offshore facilities. However, there are examples of successful offshore commercial production facilities as well as prototypes being tested for a variety of aquaculture species (Forster, 2008; Lovatelli et al., 2013).

While hundreds of species are currently raised in freshwater, land based, and coastal aquaculture facilities, only a few have the potential to be produced offshore at a commercial scale (Lovatelli et al., 2013). Each species has its own specific husbandry techniques and technology needs. The following sections briefly describe the current and emerging technologies for each of three species categories (finfish, shellfish, and marine plants) to provide context to what offshore aquaculture could look like in the MSP Study Area.

Finfish

Atlantic salmon (*Salmo salar*) have been commercially cultivated in net pens in Puget Sound since the 1970's (Ladenburg & Sturges, 1999), and British Columbia is also home to a major Atlantic salmon aquaculture industry (Fisheries & Ocean Canada, 2013). Atlantic salmon are also successfully cultivated in deep water and weather exposed sites in Norway and Chile (Holmer, 2013). Given the commercial market success of Atlantic salmon (Lovatelli et al., 2013) and the presence of Atlantic salmon cultivation in the Pacific Northwest, Atlantic salmon may be a likely candidate for offshore aquaculture in Washington. A few current and emerging cage designs are suitable for offshore finfish cultivation, utilizing various materials and structural systems. The following is a brief discussion of two main types of cage designs for finfish: surface and submersible cages.

Surface cages

Surface cages, or net pens, have continuous surface exposure and cannot be submerged under the water. These cages often are composed of netting which is flexible and attached to a floating collar at the water's surface. This flexible collar will float and bend to adapt to rough waves (Forster, 2008). The use of floating net cages has been conducted at many exposed and offshore sites, yet there are limitations to their use. Strength and endurance of the cages are limited, and there are issues with volume loss, worker safety, and other operational limitations at exposed offshore sites (Ladenburg & Sturges, 1999). It is anticipated that nearshore net pen technology will continue to evolve and be adapted for offshore operations.

There are also rigid platform cages with surface access designed to resist waves through the strength of the structure (Forster, 2013). Another design is to have mobile platforms utilizing a barge or ship system, but this is quite costly and would need to be vast in size (Ladenburg & Sturges, 1999).

While surface cages are more exposed to rough sea surface conditions compared to submersible cages, they are highly attractive because there is easy surface access for operations (Ladenburg & Sturges, 1999).

Submersible cages

Submersible and semi-submersible cages are designed so that the surface of the fish cage is submerged for extended periods of time or specifically during rough seas. These designs are intended to minimize exposure to storms. There are several operational designs for submersible cages, some with rigid outer structures and some with nets and a central spar (Ladenburg & Sturges, 1999). The cages are brought to the surface for servicing operations such as harvesting and cleaning. Ocean Spar Technologies, a company based in Washington, has designs for nearshore and offshore submersible finfish culture cages. A Russian cage technology called the Sadco-Shelf Submersible Cage has been located up to 50 miles offshore (Ladenburg & Sturges, 1999).

An advantage of a submersible cage design is that it can withstand an increasing range of exposed, rough sea conditions. It has been speculated that as technology for remote monitoring and operations improves, submerged cage methods may dominate offshore aquaculture in the future (Forster, 2008), as long as they are cost effective at commercial scales.

Shellfish

The two main coastal aquaculture shellfish currently grown in Washington are Pacific oysters (*Crassostrea gigas*) and Manila clams (a.k.a. Japanese carpet shell) (*Venerupis philippinarum* also referenced as *Ruditapes philippinarum*). Small amounts of blue mussels (*Mytilus edulis* and other subspecies) and Kumamoto oysters (*Crassostrea sikamea*) have also been cultivated in Grays Harbor and Willapa Bay in recent years (Industrial Economics Inc., 2014).

Blue mussels and other mussel species have been tested at offshore sites in the Mediterranean, Atlantic Canada, New Zealand, and northeastern United States of America (Lovatelli et al., 2013). Mussels and scallops are cultured using longlines. Floating submersible longlines are moored to the bottom, and the shellfish are attached to the lines or grown in net bags (Forster, 2008, 2013). Several longline techniques have been adapted to a variety of offshore conditions (Forster, 2013; Lovatelli et al., 2013).

The technology is further along for offshore shellfish aquaculture than for finfish aquaculture. Shellfish extract food from the water column, which facilitates the option of growing them in harsh environments. However, shellfish aquaculture is not without challenges. The weight of the shellfish as they grow can influence the appropriate depth of the lines and vertical motion can cause mussel detachment (Lovatelli et al., 2013).

Marine plants

Marine plants dominate the global aquaculture industry by tons produced, but fall beneath both finfish and crustacean aquaculture for unit value (Lovatelli et al., 2013). Offshore seaweed culture is similar to that of shellfish. The seaweeds are attached to submerged longlines with floats that are moored to the bottom. Because of light requirements, however, the surface area required to grow seaweed in the ocean is likely greater than for finfish and shellfish and therefore adds to the challenge of cultivating seaweed offshore (Forster, 2013).

Potential benefits and use compatibilities

Seafood demand and food security

In 2012, commercial aquaculture contributed half of the world's seafood. The United States imports about 80-90% (by value) of its seafood, and half of that is from international aquaculture (Interagency Working Group on Aquaculture, 2014). Domestic marine aquaculture supplies about 1.5% of American seafood demand (Rubino, 2008). The overall seafood trading deficit in 2012 was about $11 billion (Interagency Working Group on Aquaculture, 2014).

Offshore aquaculture presents an opportunity to expand domestic aquaculture to meet increasing domestic and global seafood demand. The growing world population combined with health expert recommendations for the benefits of seafood consumption will continue to increase demand for seafood, while wild capture fisheries will be unable to meet this rising demand (Rubino, 2008). Aquaculture increases seafood supply and reduces supply uncertainty. An expanded domestic aquaculture industry can provide Americans with healthy, consistent, and affordable seafood products

(Interagency Working Group on Aquaculture, 2014; Rubino, 2008). Offshore aquaculture may have a greater potential to meet this demand compared to coastal aquaculture, as limitations on space and high occurrences of competing uses are more pronounced in coastal and estuarine waters (Rubino, 2008).

Food health and environmental health

There are many potential advantages to offshore aquaculture in the United States and in Washington's waters. Offshore aquaculture products will be subject to U.S. and Washington State health and environmental regulations and enforcement (just as current coastal aquaculture is), whereas other countries have a wide range of health and environmental regulations and oversight. Offshore aquaculture products grown in the U.S. could help meet the increasing demand by American consumers for access to safe, local, and sustainable seafood products.

Offshore aquaculture is usually located in deep waters, generally with well-mixed water and currents which can dilute nutrients and particles generated by finfish. In addition, because they are located further from shore, they will be subjected to reduced exposure to land-based pollutants compared to coastal aquaculture (Holmer, 2013; Knapp, 2008a). The Pacific Northwest coast has clean, naturally productive water, which is advantageous to growing healthy seafood and healthy products for consumers (Langdon, 2008). Offshore sites may also pose a reduced risk of transmitting diseases and parasites to native fish populations, especially if sited away from major migration, feeding, and spawning areas (Holmer, 2013).

Economic impacts

Offshore aquaculture in Washington has the potential to contribute to the local, state, and national economy. Even though offshore aquaculture is trending more toward remotely operated facilities, employees will still be needed for site operations, husbandry, maintenance, monitoring, transportation, and seafood processing. The Pacific Northwest, especially Washington State, has a strong history of coastal aquaculture (Anderson & Forster, 2008; Industrial Economics Inc., 2014), and therefore may be well suited to provide local and regional expertise to offshore operations. Local shellfish and salmonid husbandry knowledge may be advantageous for successful offshore operations (Rust, Langan, & Goudey, 2008). There are also potential opportunities for commercial fishermen to become involved with offshore aquaculture, such as through jobs in navigation utilizing current vessel ownership and knowledge of ocean conditions. For example, the commercial offshore finfish operations in Hawaii and Puerto Rico were started by individuals with commercial fishing backgrounds (Rubino, 2008; Valderrama & Anderson, 2008).

The potential economic benefits of offshore aquaculture are not restricted to just the on-site operations. Offshore aquaculture also has the potential to support working waterfronts and other industry-related facilities (Valderrama & Anderson, 2008). Washington's coast has seafood processing and distribution systems in place which may benefit from increases in seafood product. There are also local and regional feed and deep water cage suppliers (Anderson & Forster, 2008; Ladenburg & Sturges, 1999). In addition, the West Coast has a strong seafood demand, which adds to a competitive advantage compared to producers in other locations (Anderson & Forster, 2008).

The overall impact of upstream and downstream products and services (cage manufacturing, juvenile supply, processing, restaurants, etc.) may be five to ten times larger than the jobs and wages at an offshore facility. This would include local, statewide, and national economic benefits (Knapp, 2008b). With a strong history of aquaculture and commercial fishing as well as existing infrastructure to support aquaculture activities, Washington's coast may be well positioned to realize many potential local and regional economic benefits associated with offshore aquaculture.

Potential use compatibilities

The use of ocean space for offshore aquaculture has the potential to be compatible or have limited conflict with some established and future uses. As mentioned above, the aquaculture industry, as well as existing ports, processing facilities, and other marine infrastructure may benefit from offshore aquaculture along Washington's coast (Anderson & Forster, 2008). Another potential compatible use is the co-location of offshore aquaculture with Marine Protected Areas (MPAs) or other protected sanctuaries. Finfish cages have been documented to act as fish aggregation areas for wild fish seeking either the feed from the operation or refuge from predators (Holmer, 2013; Price & Morris, 2013). Some studies have shown that wild fish presence at finfish cages helps to reduce benthic impacts (Price & Morris, 2013). There may be an opportunity to place these cages in locations already under fishing restrictions (L. E. Buck, 2012), provided there is no significant negative impact to the surrounding habitats or organisms. MPAs and offshore aquaculture may also be conflicting uses, which is discussed further in the Potential Impacts section.

A potential compatible use is marine renewable energy. Combining renewable energy structures with mussel and seaweed aquaculture may be feasible (Holmer, 2013), but further exploration and testing is necessary.

As offshore aquaculture operations are located further from shore, it is expected that fewer space and use conflicts will occur (Knapp, 2008a). Decreased visual impact from facilities the farther they are located from shore is but one example of this (Ladenburg & Sturges, 1999).

Potential impacts and use conflicts

Ecological impacts

Many of the environmental concerns associated with marine aquaculture relate to finfish aquaculture specifically, and some impacts are predicted to decline when locating aquaculture at deeper, offshore sites. Water quality impacts such as increased levels of phosphorus, nitrogen, and turbidity are generally not detected at offshore sites (Price & Morris, 2013). In general, water quality impacts have been greatly reduced at coastal finfish aquaculture sites over the past 20 years due to increases in feeding efficiency and food composition. Well-flushed, offshore sites in deep water are expected to have no observable impact to water quality (Price & Morris, 2013).

One of the main concerns with finfish aquaculture is the effect of excess food particles and feces accumulating on the seafloor. Changes in benthic chemistry and community composition have been observed beneath and adjacent to coastal finfish cages. However, this effect may be reduced by appropriate siting in well-flushed, erosional areas as well as remediated through fallowing practices. Offshore sites are expected to exhibit lesser changes to the sediment, yet appropriate siting to minimize changes to the sediment is highly recommended (Holmer, 2013; Price & Morris, 2013). Offshore sites should also avoid deep-sea sensitive habitats, as they may take longer to recover (Holmer, 2013). Larger and more numerous aquaculture facilities may also have an impact as there may be a potential for benthic effects from cumulative nutrient loading, especially in poorly flushed areas (Price & Morris, 2013).

Another topic of concern is the interactions between the aquaculture structures and other marine organisms, such as sharks, pinnipeds, seabirds, and wild fish. Wild fish may aggregate around fish cages and may be attracted by the feed or use the structure for protection from predators. There is little published literature on the interactions between sharks, seabirds, and pinnipeds (Price & Morris, 2013). Fish cages can influence marine mammal behavior and cause injury, stress, or death by entanglement. Pinnipeds can also cause financial losses to the fish facilities through direct predation, or by causing stress and escapement of fish from predator attacks (Price & Morris, 2013).

In general, to avoid interactions and predation from pinnipeds and other marine species, experts suggest that finfish cages be sited away from known aggregation areas, migration routes, and haul-out sites. Strong and taut predator exclusion nets will decrease risk to the cultivated fish and to predators. Also, practices such as removing dead fish may reduce the attraction from sharks (Price & Morris, 2013; Sims, 2013). Best management practices for aquaculture facilities such as taut nets and anchor lines, predator resistant cages, and limited underwater lighting is expected to minimize negative interactions with wildlife (Nash, Burbridge, & Volkman, 2005).

Chemical contaminants such therapeutants[1], antibiotics, and anti-foulants[2] are consistently identified as concerns for marine aquaculture, but the use of these products has drastically declined over the past 20 years (Price & Morris, 2013). While the risk from these chemicals is considered to be lower than in the past, further research is recommended on impacts to non-target organisms (Price & Morris, 2013). Heavy metals from cages can also accumulate under cages. Studies show these concentrations to be low and heavy metals are typically bound to the sediment (Price & Morris, 2013).

Potential disease and parasite transmission from cultured fish to wild fish is a concern (Holmer, 2013; Leonard, Kent, & Banks, 2008). State and federal regulations are in place to prevent novel diseases from entering Washington's waters, as well as prevent disease spread in the event of an outbreak (RCW 77.60; RCW 77.115; WAC 220-76; WAC 220-77; 9 CFR 53.10; 9 CFR 71.2; 9 CFR 93.900-906). Offshore sites are also expected to have a reduced risk of transmitting diseases and parasites because of the potential increased distance between the operations and if they are sited away from major wild fish migration routes (Holmer, 2013).

Economic impacts

One of the economic concerns associated with offshore aquaculture is the market effect on wild capture fisheries. Certain aquaculture products will directly compete in the market for wild capture fisheries. This effect has already been seen with global Atlantic salmon coastal aquaculture competing with wild capture salmon fisheries. Increases in Atlantic salmon availability may reduce overall salmon prices, which benefits the consumer, but negatively impacts wild capture salmon fishermen. This impact is expected to be temporary (Knapp, 2008b). It has been hypothesized that cultured Atlantic salmon may create niche markets for wild caught salmon, which may increase demand and create a premium price for wild capture fish (Knapp, 2008b; Valderrama & Anderson, 2008). As seafood becomes more readily available, consumers may be more receptive to seafood and this in itself will increase overall demand. As demand increases, including demand from a growing population, the effects of higher supply from aquaculture will likely be partially offset and, therefore, reduce the decline in fish prices (Knapp, 2008b).

Regardless of Washington's participation in offshore aquaculture or aquaculture operations in general, world demand for seafood is increasing. Other countries will likely boost aquaculture production to meet this demand, and the competition with wild capture fishermen will then occur

[1] Therapeutants are medications used to treat parasitic, viral, fungal, and bacterial infections as well as to treat aquaculture facilities (Price & Morris, 2013).

[2] Anti-foulants are treatments used to control or eliminate the growth of marine organisms on aquaculture cages, ropes, and structures. (Price & Morris, 2013).

whether or not cultured seafood is domestic or international. Experts speculate that the specific economic effects of domestic aquaculture on domestic fishermen will be relatively small compared to the larger effects of the growing global aquaculture industry (Knapp, 2008b).

Potential use conflicts

Offshore aquaculture has the potential to conflict with some current and future uses of Washington's ocean. Some concerns related to spatial conflicts include: competition with commercial fisheries, recreational fisheries, recreational activities (boating, aesthetics, etc.), shipping, military uses, cable installation, marine animal migration routes, mining, dredging, and dredge disposal (L. E. Buck, 2012; Hildenbrand & Feldner, 2008). The cages, longlines, and moorings create space and safety conflicts for navigation, fishing equipment, and SCUBA diving. An offshore operation in Hawaii has established restrictions on these types of activities within the site (Sims, 2013). Offshore aquaculture may also pose a space conflict with marine renewable energy (Hildenbrand & Feldner, 2008), in the event that aquaculture and energy operations are not compatible. However, offshore aquaculture and marine renewable energy may be compatible due to the potential for these uses to occupy the same spatial footprint by utilizing shared support infrastructure (B. H. Buck, Ebeling, & Michler-Cieluch, 2010).

Potential environmental conflicts, which are most often associated with finfish aquaculture, include marine reserves, sensitive habitats, and marine animal migration routes. Potential impacts to benthic communities and possible negative interactions with fish and other marine species may be in conflict with the goals of marine reserves. In addition, mooring lines from cages and longlines may pose a risk of animal entanglement. Interactions of seabirds, pinnipeds, and other marine mammals with offshore aquaculture may pose conflicts, particularly along major migration routes and aggregation sites (Price & Morris, 2013).

Potential along Washington's Pacific Coast

Currently, no offshore aquaculture exists along Washington's Pacific coast. However, there is potential for future offshore aquaculture. Washington currently has coastal shellfish and finfish commercial aquaculture operations, ports and other marine infrastructure, and oceanographic conditions generally favorable to support offshore aquaculture (Anderson & Forster, 2008; Industrial Economics Inc., 2014). The realization of offshore operations, however, largely depends upon economic feasibility as well as available technology for safe and quality aquaculture operations (Forster, 2013; Knapp, 2013). Whether and where offshore aquaculture facilities are located along the Washington coast will depend upon factors including cost-effective technological feasibility, environmental considerations, and social acceptance. Some key factors to consider include:

- **Depth**- Depth is a limiting factor for where offshore aquaculture can be located. Mooring technology is available up to 100 m (Kapetsky, Aguilar-Manjarrez, & Jenness, 2013) and most sites may be restricted 75 m or shallower due to prohibitive mooring costs (Forster, 2013). On the other hand, deeper water generally indicates fewer environmental impacts. So depending upon the size and intensity of the operation, minimum depth thresholds may be encouraged to minimize environmental conflict (Price & Morris, 2013).
- **Space Conflicts**- As mentioned above, space conflicts with existing and future uses may occur. Therefore, locating offshore aquaculture at locations that will avoid significant conflict with established users such as commercial fisheries and recreational activities is an important factor to consider.
- **Conditions suitable to culture a selected species**- The oceanographic and physical conditions of a site must be suitable to successfully culture a commercially profitable species.

- **Access to ports, processing facilities and markets**- Access to ports and existing marine infrastructure is critical for commercial success. It will be more profitable, and therefore feasible, for offshore aquaculture to build off of existing structure than to create new ports, facilities, and transport to markets. Offshore operations are unlikely to be located more than 25 nautical miles from existing ports (Jin, 2008; Kapetsky et al., 2013).
- **Proximity to sensitive habitats**- Finfish aquaculture may have an impact to sensitive habitats directly below or down drift of the cages. Therefore, locating these sites to avoid particularly sensitive habitats such as corals or seagrass is an important environmental factor (Holmer, 2013; Price & Morris, 2013). Offshore shellfish or marine plant growing operations should also avoid any shade impact to light sensitive habitats such as seagrass (Holmer, 2013).
- **Well flushed, erosional sediments (finfish)**- Environmental impacts are expected to be minimal at well sited offshore locations. Siting for offshore finfish aquaculture should be in areas with deep, well flushed waters over erosional sediments to avoid environmental impacts (Price & Morris, 2013).

A forum was hosted in 2008 by Oregon State University to discuss the potential of offshore aquaculture in the Pacific Northwest. Some of the advantages identified by participants for offshore aquaculture in the Pacific Northwest include optimal water temperatures, suitable substrate for moorings, and naturally productive waters. Other advantages of this region related to services include salmonid hatchery and husbandry experience, local and regional feed and deep water cage suppliers, and existing seafood processing and distribution systems. The forum also referenced the strong seafood market demand in the Pacific Northwest (Anderson & Forster, 2008).

While it was recognized that there is real potential in Pacific Northwest waters, some challenging factors exist such as the number of stormy days along this coast, competition concerns by the commercial fishing industry, and environmental concerns from the public (Anderson & Forster, 2008). Participants indicated the need for access to cost effective technology (Rust et al., 2008) and a better understanding of potential disease transmission and animal interactions with offshore aquaculture (Leonard et al., 2008).

The availability of culture technology that can withstand the conditions off the Washington coast at a cost effective price is a main determinant of commercial offshore aquaculture feasibility. Safe and consistent access for workers is also a key factor as well as clear state and federal regulations for offshore operations (L. E. Buck, 2012; Forster, 2013; Rubino, 2008). As technology continues to evolve, materials become more reliable and affordable, coastal sites become limited, and seafood demand increases, the more likely aquaculture will expand into offshore waters (Knapp, 2008a, 2013).

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2.10.3 Dredging and Dredge Disposal

Dredging and dredge disposal are essential activities that are already ongoing in the MSP Study Area. They are included in this section of the MSP to address the potential for expansion of this use in the future. The MSP provides an opportunity to guide state and federal regulatory authorities on locating future disposal sites to avoid conflict with existing uses and maximize beneficial use of dredged material.

Summary of history and current use

Dredging is essential for port and harbor access and navigational safety. Navigation channels and harbors naturally fill up with sand and mud over time. Dredging removes this material, which is then disposed of at in-water or on-land locations. Without dredging, navigation channels and harbors can become unsafe for navigation or inaccessible altogether. The commerce brought in through shipping and access to ports and marinas is an important part of the Washington Pacific coast region and statewide economy (Dredged Material Management Program, 2012). Therefore, dredging plays a critical role among the established and expanded uses of Washington's marine waters.

Dredging and dredge disposal have had a long history along Washington's Pacific coast. Congress first authorized jetty construction and maintenance dredging for federal navigation channels in Grays Harbor and the Mouth of the Columbia River in the late 1800s. These navigation channels have been deepened over time to accommodate large, deep-water cargo vessels. The U.S. Army Corps of Engineers (Corps) is responsible for maintenance dredging of the navigation channels in Grays Harbor (Map 51) and the Mouth of the Columbia River (Map 52). The navigation channel in Grays Harbor supports the Port of Grays Harbor terminals and facilities. The Mouth of the Columbia River navigation channel supports several ports along the Columbia River.[1]

Several small ports with harbors and marinas along the MSP Study Area also require dredging to maintain boat access for commercial and recreational fisheries, aquaculture, and other uses. There are four small port facilities within Willapa Bay (Map 53). The Port of Willapa Harbor owns and operates Raymond Port Dock, Bay Center Marina, and Tokeland Marina. The Port of Peninsula operates the marina at Nahcotta. Two tribal-owned facilities also occur within the MSP Study Area, the Quinault Marina in Ocean Shores and the Quileute Marina in La Push (Map 30).

The disposal of dredged material is a critical component of dredging activities. Dredged material is disposed of at in-water or upland sites. Disposal of material at in-water sites is generally the economically preferred alternative. Sediment disposed at nearshore sites can provide opportunities to keep the sediment near the coast to replenish beaches. Sediments determined to be unsuitable for in-water disposal, such as sediments from chemically contaminated sites, are disposed of at approved upland locations (Dredged Material Management Office, 2013).

The Washington Department of Natural Resources (DNR) manages six in-water disposal sites within the MSP Study Area, four for Grays Harbor (Map 51) and two for Willapa Bay (Map 53). All of these sites are categorized as dispersive, meaning that dredged material will eventually disperse and leave the immediate site as opposed to staying in place. Actively used sites are monitored by the Corps regularly for volume capacity and other parameters (Dredged Material Management Office, 2013).

[1] Ports along the Columbia River are outside of the MSP Study Area.

Beneficial use sites are disposal locations where dredge material is deposited for some specific beneficial purpose or reuse of the material[2], such as erosion mitigation or dune restoration. There are a few beneficial use sites within the MSP Study Area, including two nearshore DNR/Corps managed sites at Grays Harbor and a couple of on-shore beneficial use projects (e.g. Quillayute River and Shoalwater Bay). State and federal regulatory agencies as well as regional sediment management teams such as the Lower Columbia Solutions Group encourage the beneficial use of dredge material over deep water disposal (Dredged Material Management Office, 2013; Oregon Solutions, Cogan Owens Cogan, & Oregon State University Institute of Natural Resources, 2011).

Flow lane disposal is an alternative in-water disposal method for approved dredged material. Flow lane disposal sites are located within natural scour channels; allowing the sediment to disperse from the site. This alternative is generally done within the Columbia River and for some dredge disposal in Willapa Bay since 2009 (Dredged Material Management Office, 2013).

Three in-water disposal sites are established within or directly adjacent to the Study Area at the Mouth of the Columbia River. Two of these sites, including a deep water site, are managed by the Environmental Protection Agency (EPA) and the other is managed by the Corps and authorized for use through the Washington Department of Ecology (Ecology).

The State of Washington recognizes the importance of dredging and properly managed disposal of dredge material. Policy recommendations made by the Washington State Ocean Policy Work Group in Washington's Ocean Action Plan (Office of the Governor, 2006) include: requiring the beneficial use of dredged materials where appropriate to deal with chronic erosion, minimizing impacts to navigation and other marine resources, regional coordination and planning, and using best available science to make decisions.

Grays Harbor

The federal government first authorized navigation improvements to the Grays Harbor navigation channel in 1896. The Corps constructed the North and South Jetties and began dredging activities in the early 1900s. The channel was maintained at -30 feet Mean Lower Low Water (MLLW) until it was deepened to -36 feet MLLW in 1990 (U.S. Army Corps of Engineers, 1982, 2014b). The Corps continues to be responsible for annual navigation channel maintenance in Grays Harbor. Although the channel is currently maintained at -36 feet MLLW, it is legislatively authorized to a depth of -38 feet MLLW (U.S. Army Corps of Engineers, 2014b). In October 2016, dredging began to deepen the navigation channel to -38 feet MLLW and is expected to be completed in late 2018 (see Future Trends and Factors for Dredging and Dredge Disposal).

The Corps uses six sites for disposal of the Grays Harbor navigation channel maintenance dredging material (Map 47). Four of these sites are DNR in-water disposal sites. The Point Chehalis open water dispersal site is the most heavily used site for dredge disposal (U.S. Army Corps of Engineers, 2014b). This 229.6 acre site is greater than 50 feet deep, located north of Point Chehalis and includes part of the navigation channel. The second DNR authorized open water dispersal site is the South Jetty site. This site is 55.1 acres and about 50 feet deep, located directly north the South Jetty's western portion (Dredged Material Management Office, 2013). Material dredged from the inner harbor is generally placed here. Material is diverted to the Point Chehalis site when the South Jetty site reaches capacity (U.S. Army Corps of Engineers, 2014b).

[2] There are upland beneficial uses of dredged material, but these are not discussed within the MSP as they are not related to the MSP Study Area.

Two nearshore beneficial use sites are managed by the DNR and the Corps in Grays Harbor. The South Beach beneficial site receives sediment from the Bar Channel navigation segment in an attempt to slow erosion along South Beach and the south side of the South Jetty. Material is generally placed at -35 to -45 feet MLLW. The second nearshore beneficial use site is the Half Moon Bay site (Map 47). The purpose of this site is to maintain a stable beach profile in the high-energy conditions of Half Moon Bay (U.S. Army Corps of Engineers, 2014b).

The fifth in-water disposal site is the 3.9 Mile Southwest Ocean site managed by the EPA (Map 47). This offshore deep-water site is used very infrequently and is currently listed as inactive in the 2013 Dredge Material Management Program (DMMP) user manual (Dredged Material Management Office, 2013).

The sixth site is the Point Chehalis revetment extension mitigation site, which is an upland shore site just above Mean Higher High Water (MHHW) managed by the Corps. Dredged material is placed to cover the Point Chehalis revetment extension and is predicted to erode over time to contribute sediment to the local nearshore system (U.S. Army Corps of Engineers, 2014b). Periodically, sediment has been excavated from this site to nourish the dune along Half Moon Bay and South Beach shorelines to address the risk of a breach at the South Jetty (U.S. Army Corps of Engineers, 2014b).

The Port is responsible for dredging the terminals and marina boat basin. The terminals are currently dredged every year using a contractor. The dredge material is disposed at the Point Chehalis or South Jetty DNR disposal sites. The Westport Marina was last dredged during its expansion in 1980. The Port is planning to dredge the boat basin in 2016 utilizing a hydraulic suction pipeline dredge and will dispose the material at the Point Chehalis WDNR site (M. Horton, personal communication, October 22, 2104). The Corps is also planning on dredging the two federally authorized entrance channels into Westport Marina in 2016. The material will be disposed at the current Grays Harbor DNR managed in-water disposal sites (U.S. Army Corps of Engineers, personal communication, September 29, 2014)

Mouth of Columbia River

Congress first authorized the federal navigation channel at the Mouth of the Columbia River (MCR) in 1884. The Corps maintains three jetties to stabilize the navigation channel. The navigation channel is maintained at -55 feet MLLW on the north side and -48 feet MLLW on the south side of the channel. The bar at the Mouth of the Columbia River is considered to be the second most dangerous bar crossing in the world. The jetties and surrounding areas are subject to frequent and intense storms, and chronic erosion of the area has occurred since completion of jetty construction in 1939 (Oregon Solutions et al., 2011).

The Corps dredges approximately four million cubic yards of sand every year. This material is disposed of at four in-water disposal sites nearby. Two are nearshore sites within Washington waters, which include the Shallow Water Ocean Disposal Site managed by the EPA located two miles offshore from the MCR, and the North Jetty Site (a Corps designated site) located about 200 feet south of the North Jetty. An EPA managed Deep Water Site is located about six miles offshore from the MCR. About one third of the dredged material from the MCR was disposed at the Deep Water Site between 2005 and 2011 (Oregon Solutions et al., 2011; U.S. Army Corps of Engineers, 2014a). Material is placed at the Deep Water Site when the other sites have reached capacity or when weather conditions or operational constraints preclude the use of the nearshore sites. Dredged material disposed at the Deep Water Site is effectively removed from the nearshore and, therefore, is considered an unsustainable use of sand material in an eroding system (Oregon Solutions et al., 2011).

Concerns for long-term erosion of the MCR jetties, spits, and nearby beaches prompted a 2011 Regional Sediment Management Plan (RSMP) that proposed an expanded network of nearshore disposal sites. The Lower Columbia Solutions Group (LCSG), a bi-state collaboration of public and private parties, drafted the plan. Proposed locations included sites on the Washington and Oregon Pacific coasts (Oregon Solutions et al., 2011). While the MCR navigation channel dredging and current dredge disposal sites are outside of the MSP Study Area, the 2011 RSMP identified two locations within the Study Area as potential sites to be a part of an expanded sediment management network (Oregon Solutions et al., 2011).

To date, on-shore placement at Benson Beach is the only 2011 RSMP proposed beneficial use site within the MSP Study Area to receive dredge material from the MCR. Benson Beach is located directly north of the North Jetty (Map 52). The 2011 RSMP recommended Benson Beach because this location was expected to have the greatest benefits for beach and drift restoration in the area. A demonstration project placed approximately 400,000 cubic yards of dredged material from the MCR onto the Benson Beach intertidal area in 2010. Funding for the project came from the State of Washington ($1.69 million) and the Corps ($1.8 million) (Oregon Solutions et al., 2011). Disposal at Benson Beach has not occurred since the 2010 demonstration project. Costs and safety concerns are barriers to the future use of this site.

Shoalwater Bay project

The Shoalwater Bay Shoreline Erosion Protection project utilizes dredging for a purpose other than navigation. The Shoalwater Bay Indian Reservation has important subtidal and tidal lands for the tribe's shellfish harvesting within North Cove in northern Willapa Bay. The tribe also has important infrastructure on a narrow strip of reservation land along the coast in this area. A natural dune system on Graveyard and Empire Spits historically protected North Cove from flooding and storm events. Due to changes in adjacent shoreline geomorphology, the dunes are no longer accreting sand and are now eroding. The dune system was breached and the Shoalwater Reservation flooded from storm and tidal events in 1999, 2006, and 2007 (U.S. Army Corps of Engineers, 2009).

To protect the Shoalwater Bay Indian Reservation land, shellfish habitat, and adjacent areas from future flood damage, the Corps funded a project to rebuild the protective dune system. This involved dredging just north of the Willapa Channel offshore from North Cove using a large pipeline dredge. The dredged material was placed on the dune system to add height and close the breach areas. The plan called for about 600,000 cubic yards of material during construction to be placed on a total of 47 acres. According to the project plan, maintenance of this project is expected to occur about every five years by removing about 250,000 cubic yards of material dredged just offshore in the Willapa Bay channel and adding to the dune (U.S. Army Corps of Engineers, 2009). The project began in 2012, took two years to complete construction, and is currently being monitored.

Small port dredging and disposal along the Washington coast

Small ports are a vital part to ocean activities and prosperity of the Washington coast. Small ports contribute hundreds of millions of dollars annually to the economy (Pacific County Economic Development Council, 2013). The maintenance dredging of small harbors is an economic and political issue, and to a great degree influenced by federal funding and decisions. It is not within the scope or power of the MSP to address federal funding for small harbors. However, context for small port funding, as well as descriptions of WA's small coastal ports within and directly adjacent to the Study Area is provided recognizing their importance to the coast and for their influence on dredging and dredge disposal activities.

Federal funding for small ports

For the past several years small coastal harbors have had to compete directly with larger coastal ports across the nation for federal funding. This has resulted in variable and uncertain funding for small port dredging (U.S. Army Corps of Engineers, personal communication, September, 2014). Dredging operations are expensive as costs include not only the dredge equipment and operation (G. Glenn, personal communication, October 22, 2014), but there are additional costs for sediment testing, fees for in-water dredge disposal at DNR sites (WAC 332-30-166), as well as costs for upland disposal. This can create a significant challenge for small ports to secure adequate funding for maintaining access channels to their harbors (R. Chaffee, personal communication, October 1, 2014).

Small ports face consequences when harbor entrance channel maintenance dredging is delayed or discontinued. In some small harbors, up to 100% of harbor activities have been reported to be dredge dependent. Significant consequences such as the relocation or closure of businesses, loss of jobs, and impacts to fisheries and recreation industries are expected if dredging for small harbors was to cease or be delayed (Pacific County Economic Development Council, 2013).

Appropriated funds for federal navigation projects are filled by the Harbor Maintenance Trust Fund. All coastal ports compete for funding from this pool of revenue. However, small (low-use) ports have the challenge of competing against high- and moderate-use ports for funding. The Water Resources Reform and Development Act of 2014 included new provisions for small harbors, which may lead to a certain portion of the overall Harbor Maintenance Trust Fund being allocated to small harbors. In 2014, Congress appropriated funds to finance navigation channel dredging for small ports across the country, including some of the small ports within and adjacent to the Study Area for 2014 (U.S. Army Corps of Engineers, personal communication, September, 2014).

Additional discussion of ports and marinas can be found in Section 2.4 Commercial, Recreational, and Tribal Fisheries and Section 2.7 Marine Transportation, Navigation, and Infrastructure.

Port of Willapa Harbor

Formed in 1928, the Port of Willapa Harbor developed port facilities for shipping lumber and other forest products as well as fishing and oyster vessels. The Port owns and operates three water access facilities within Willapa Bay that require various frequencies of dredging for navigation maintenance: Tokeland Marina, Bay Center Marina, and the Raymond Port Dock (Map 53). Currently, the Port facilities support the timber industry, commercial and recreational fishing, oyster harvesting, tourism, retail, offices, and other industrial services (“Port of Willapa Harbor,” n.d.).

The Corps historically dredged a federal navigation channel and harbor entrance channels in Willapa Bay, first authorized in 1892, and worked with the Port to keep the Port facilities dredged for shipping and boat access. The Corps activities included the main channel which dredged the bar at the mouth of Willapa Bay and continued to the Willapa River, as well as a few connection channels to harbors within the Bay. In 1975 the Corps discontinued the dredging of the main channel over the bar at the mouth of the Bay to the Willapa River due to funding restrictions. Since then, commercial ocean vessels have not been able to access the ports of Willapa Bay. The Corps continued to dredge the entrance channels connecting the marinas to the naturally deep channel of Willapa Bay until the early 2000s (Ott, 2011).

The Port of Willapa Harbor secured a grant and loan to purchase a small hydraulic suction dredge in 2009. They have used this dredge to maintain the boat basin at Tokeland Marina, as well as the entrance channel which connects Tokeland to the deepwater channel. Recent dredging at Tokeland and the associated entrance channel has taken place in the 2010, 2011, and 2012 seasons. The learning curve of operating their own dredge required three seasons of operations to initially dredge the marina, but their long term plan is to dredge once about every four years. The most recent dredging activity at Tokeland was in the 2014-15 season (R. Chaffee, personal communication, October 1, 2014).

The Bay Center boat basin is located within the federally authorized channel at the Palix River in Willapa Bay (R. Chaffee, personal communication, October 1, 2014). Bay Center was last dredged by the Corps in 2002 (Coast & Harbor Engineering, 2011). Dredging at Bay Center using the Port's dredge occurred in the 2013-14 season, and the Port anticipates that it will be dredged approximately every four years (R. Chaffee, personal communication, October 1, 2014). The Port is also looking into dredging at the Raymond Port Dock. Funding for dredging comes from the Port of Willapa Harbor budget. The Port is planning to work with local partners to utilize the Port's dredge at city, Port, and private docks throughout Willapa Bay (Coast & Harbor Engineering, 2011; R. Chaffee, personal communication, October 1, 2014).

When the Corps was actively dredging in Willapa Bay, two DNR in-water sites were used: Cape Shoalwater and Goose Point (Map 53) (Coast & Harbor Engineering, 2011). Both of these sites are open-water dispersive sites (Dredged Material Management Office, 2013). In addition, an upland disposal site at Tokeland was historically utilized, but this site has reached capacity (R. Chaffee, personal communication, October 1, 2014). The Port now uses flow lanes to dispose of dredged material from the boat basins and entrance channels. The flow lanes are directly adjacent to the project areas, located in deep water with natural scour and sediment transport. The use of flow lanes is beneficial to the Port because transport of material to the DNR sites is either infeasible or impractical for the small dredging equipment (Coast & Harbor Engineering, 2011), and flow lanes are much more cost effective than upland disposal (R. Chaffee, personal communication, October 1, 2014).

Work has been started by the Port to identify flow lanes near other city, Port, and private water-dependent facilities throughout Willapa Bay for future maintenance dredging operations (Coast & Harbor Engineering, 2011). The only recent funding from the Corps has been for sediment characterization of potential dredge locations throughout the Bay (R. Chaffee, personal communication, October 1, 2014).

Port of Peninsula

The Port of Peninsula owns a commercial facility in Nahcotta, WA located on the Willapa Bay side of the Long Beach Peninsula (Map 53). The Port of Peninsula shares a similar history with the Port of Willapa Harbor in regards to Corps support for dredging. Dredging of the Willapa Bay bar and main channel was discontinued in 1975 and the Corps suspended dredging of the Ports' entrance channels in the early 2000s due to budget constraints (R. Chaffee, personal communication, October 1, 2014). The Port of Peninsula was last dredged in 2005. Historically, the Corps has disposed of dredged material at the Goose Point open water DNR site or at an upland location at Nahcotta.

An analysis for suitability of a future flow lane disposal site near the Port has been conducted (Coast & Harbor Engineering, 2011). Due to the increased significance of the shellfish and fish landings at the port, the Port of Peninsula hopes to work with the Corps on future dredging needs. The Port or Corps may work with the Port of Willapa Harbor or the Port of Ilwaco to utilize their small dredges for future maintenance dredging operations at Nahcotta (Cook, 2012; M. Delong, personal communication, October 8, 2014).

Quinault Marina

The Quinault Tribe owns the marina at Ocean Shores, WA near the north side of the mouth of Grays Harbor. The marina is currently closed due to needed dredging and infrastructure repairs, although some small vessels still use it (J. Schumacker, personal communication, November 11, 2016).

Quileute Harbor Marina

The Quileute Tribe owns a harbor in La Push, WA located in the northern section of Washington's Pacific Coast at the mouth of the Quillayute River (Map 54). The Quileute Port Authority works with the Corps for maintenance dredging of the navigation channel and harbor. The channel and harbor are generally dredged by the Corps about every two years. The most recent dredging activity was in 2011 and 2014. The source of federal funding for dredging is similar to that of other small ports (U.S. Army Corps of Engineers, personal communication, September, 26, 2014).

Dredged material is disposed at a couple of locations. The dredge material from the outer channel is placed at an upland location and the material from the inner channel and harbor is placed on the ocean side of Rialto Beach Spit for beneficial use (U.S. Army Corps of Engineers, personal communication, September, 26, 2014) and occasionally near the jetty near First Beach for jetty maintenance and protection.

Significant ports outside of the Marine Spatial Plan Study Area

The Port of Ilwaco, Port of Chinook, and Port of Neah Bay are located outside of the MSP Study Area, yet provide critical services to important uses within the Study Area and contribute significantly to coastal economy. Each of these ports rely on dredging to maintain their activities and services to support the local and regional communities of Washington's Pacific coast. However, because the dredging and dredge disposal for these ports do not occur within the MSP Study Area they are not discussed further here. Each of these ports is included in Section 2.7 Marine Transportation, Navigation, and Infrastructure.

Related infrastructure

Dredging and dredge disposal methods and equipment

Material is dredged from navigation channels and harbors utilizing dredge equipment such as a hydraulic suction or clamshell dredge. The material is then stored either in hopper dredges or on barges, which can transport the sediment to disposal sites (U.S. Army Corps of Engineers, 2014b). Smaller dredges have a limited transport distance (Coast & Harbor Engineering, 2011). A number of methods can be used to release dredge material into a disposal site such as bottom-dump, dispersed spraying, and pump ashore.

Bottom-dump disposal

Barges and hopper dredges have designs for releasing the dredged material from the hull, otherwise known as bottom-dump. Bottom-dump barges and hopper dredges release the material within the boundaries of the in-water disposal sites. This method of disposal can be performed at open-water and nearshore beneficial use sites. However, safely navigating these large vessels at the shallow beneficial use sites can be a challenge (Oregon Solutions et al., 2011; U.S. Army Corps of Engineers, 2014b).

The bottom-dump disposal method at shallow, beneficial use sites can cause mounding of the material, which can result in significant wave amplification. Mound height is influenced by vessel speed, water depth, and discharge technique (open or partially open bottom doors). Thin-layer dispersal (also referred to as enhanced dumping) through the bottom-dump disposal method can be achieved by moving the vessel during disposal, thereby reducing the mounding of sediment on the seafloor. Safety considerations generally require that the hopper dredge start at the closest point to the shore and travel away from the shore perpendicularly into the waves (U.S. Army Corps of Engineers, 2012a). The Lower

Columbia Solutions Group recommended thin-layer dispersal of no more than 12 cm mound depth at the MCR proposed nearshore shallow sites (Oregon Solutions et al., 2011).

Pump-ashore disposal

Pump-ashore disposal is the placement of material directly onshore. This is achieved by mixing the sediment with water to create a slurry and hydraulically pumping the slurry through a pipeline to the onshore site (U.S. Army Corps of Engineers, 2014b). While pump-ashore disposal has many benefits, including replenishing eroding beaches, protecting jetties, and avoiding in-water mounding and associated wave-amplification, there are significant operational and financial challenges compared to traditional (bottom-dump) disposal approaches (Oregon Solutions et al., 2011).

Dispersed spraying of reliquified sand (rainbow spray)

Dispersed spraying of reliquified sand, also known as rainbow spray or pump-off disposal, is a method which mixes the dredged sediment from a hopper dredge with water to create a slurry. The slurry is then sprayed over a disposal area. This method has been recognized by the LCSG to minimize the mounded layer of sediment at nearshore disposal sites, thereby reducing the risk to benthic species and navigational safety. However, the time it takes to dispose of dredged material through this method is significantly longer than a traditional bottom-dump approach, and is therefore much more costly. There is also limited dredge equipment capable of this spray disposal method. Therefore the practical use of reliquified sand is limited (Oregon Solutions et al., 2011).

Jetties

River outlets along the WA coast often consist of areas with very shallow, shifting sands. Before manmade alterations to Grays Harbor and the MCR there was no defined channel suitable for safe, consistent navigation. Jetties were built to focus a defined, deep water channel for navigation access at the Mouth of Grays Harbor and the MCR. The MCR has three jetties (north, south, and jetty “A”) and Grays Harbor has two (north and south).

Jetties are hard structures, built on shallow shoals and extend like fingers out into the water. Jetties work by forcing the water flow between them, thereby restricting the entrance for the water. Because of these narrowed zones, the constricted water flow flushes out the shallow sand bars. This induced, deeper channel increases suitability for navigation. Maintenance requirements include repairing the jetties over time if they become damaged from storms or erosion as well as dredging of any shoals that may form despite the presence of the jetties.

Jetties at the MCR and the Mouth of Grays Harbor have impacted sediment movement along the WA coast. It can be difficult to determine the exact magnitude of these changes, simply because little was known about the geomorphology of this area before the jetties were constructed. However, it is clear that the presence of some of these jetties has facilitated coastal land accretion, which now supports infrastructure, such as the City of Ocean Shores. Therefore, jetty maintenance is not only critical for navigation, but also to communities that rely on the jetty’s physical alteration of coastal landforms (G. Kaminsky, personal communication, September 10, 2014).

Groins look similar to jetty structures, but serve a different function. Groins are structures perpendicular to the shore that are intended to affect sediment migration along the shore. They improve sediment retention in some areas along the coast, but can increase erosion in other areas. Unlike jetties, they are not intended to focus water flow for a navigation channel. Other structures such as revetments and wave diffraction structures can be associated with jetties and harbors, and essentially serve to protect these areas from waves, storm damage, and erosion.

Beneficial use disposal sites

Beneficial use of dredged material is the placement of material at a site for a specific benefit (Dredged Material Management Office, 2013). Uses for beneficial placement can be broad, such as placement for erosion control, dune reconstruction, beach nourishment, and other productive purposes. Disposal of dredged material at offshore, deep water disposal sites, such as the EPA-designated Deep Water Ocean Disposal Site at the MCR, effectively removes the sediment from the nearshore system. This removal of natural sediment from a system can "starve" coastal beaches and nearshore areas of sand, reduce protection from erosion, coastal storms and flooding, and impact marine habitat (Oregon Solutions et al., 2011).

Nearshore and onshore beneficial use sites are intended to keep the sediment within the nearshore system. For larger projects, such as Grays Harbor and MCR, a network of sites is used to optimize the opportunities for beneficial placement of material, and minimize the use of deep-water sites. Beneficial sites are typically chosen with the goal to maximize benefits to beach erosion protection, habitat improvements, and jetty protection while also minimizing the conflicts to users of the area; all the while remaining cost effective (Oregon Solutions et al., 2011; U.S. Army Corps of Engineers, 2012b, 2014b). Dredging projects may also use beneficial placement for dune enhancement or other local projects (e.g. Shoalwater Bay) (U.S. Army Corps of Engineers, 2009). Beneficial placement in support of beach habitat and to mitigate beach erosion may also positively influence recreational users (U.S. Army Corps of Engineers, 2012a).

Depending upon the location and disposal methods, placement of material at beneficial use sites can be more time consuming, require additional equipment, experience timing constraints, have safety and logistical considerations, and have higher costs. Site capacity, weather, and user conflicts also create additional challenges to nearshore and onshore beneficial placement compared to deep water placement. User conflicts for nearshore beneficial use sites include wave amplification due to mounded material in shallow water and concerns related to impacts on Dungeness crab (Oregon Solutions et al., 2011; U.S. Army Corps of Engineers, 2014b)(see Human use conflicts with disposal).

Onshore beneficial use sites, such as material placed at Benson Beach, have added benefits of avoiding user conflicts for navigation and minimizing potential impacts to Dungeness crab and the fishery. Onshore projects, however, are typically estimated to have higher costs and time requirements and different equipment needs than nearshore projects, creating additional challenges for the consistent and effective use of onshore sites (Oregon Solutions et al., 2011; U.S. Army Corps of Engineers, 2012a).

Disposal site capacity and sediment dispersal

Dredge disposal sites utilized by the Corps are actively monitored and managed for capacity. Open water sites are designed to be dispersive, meaning that the sediment placed there will disperse over time, ideally allowing for the continued long-term use of the site for annual dredge disposal (U.S. Army Corps of Engineers, 2014a). The amount of dredged material that can be placed in an open water placement site is limited by the site's capacity to accumulate and disperse the material without adversely affecting the environment or navigation. Capacity is assessed through a number of parameters, including historical baseline data, wave models, and present conditions. The natural environment (waves, storms, etc.) can influence the dispersion rates on short term and long-term scales as well as be variable within site boundaries (U.S. Army Corps of Engineers, 2014a).

Flow lane disposal

Flow lane disposal is the spreading of dredge materials in deepwater locations with natural scour. Sediment disposed in flow lanes is dispersed and is intended to have no measurable impact to bathymetry or the environment (Coast & Harbor Engineering, 2011). Therefore, issues related to sediment mounding are typically not a concern for flow lane sites. Considerations for flow lane sites include depth, bathymetry, flow velocity data, bottom sediment characteristics, and volumes of dredge to be disposed (Coast & Harbor Engineering, 2011). Along the Pacific coast of WA, flow lanes are used for projects with relatively small volumes of dredged material, such as harbor and entrance channel dredging in Willapa Bay and port entrance channel dredging in the Columbia River (Dredged Material Management Office, 2013; R. Chaffee, personal communication, October 1, 2014; U.S. Army Corps of Engineers, personal communication, September, 2014).

Impacts from dredge disposal

Environmental impacts from dredge disposal

The study of dredge disposal impacts to ocean habitat and species has a long history on the Washington coast. The Lower Columbia Solutions Group (LCSG) has compiled over a decade of research and findings from policy workshops related to environmental disposal concerns in the Mouth of the Columbia River region. Their key findings presented in the Mouth of the Columbia River Regional Sediment Management Plan (Oregon Solutions et al., 2011) are summarized below. Additional environmental details from other Washington Pacific coast dredge disposal sites are included when available.

Dungeness crab

Dungeness crab (*Metacarcinus magister*) is the species of primary concern from both biological and economic perspectives (Oregon Solutions et al., 2011). The Dungeness crab fishery is a well-established fishery that contributes tens of millions of dollars annually to Washington's coastal economy (Industrial Economics Inc., 2014). Heavy use by the Dungeness fishing fleet occurs in the southern portion of the MSP Study Area, in water depths generally less than 150 feet near the MCR region. The MCR is also important breeding and nursery habitat for Dungeness crab (Oregon Solutions et al., 2011).

Nearshore placement of dredge material is expected to contribute to the local nearshore system at the MCR when placed 65 feet deep or less. The LCSG recommended placing dredge material nearshore and onshore for beneficial use to maintain the sediment budget and control erosion. Because nearshore areas at the MCR are heavily used by Dungeness crab and crab fishermen, fishermen and others have concerns related to the effect that nearshore dredge disposal may have on the crab populations in these areas (Oregon Solutions et al., 2011).

Highlighted concerns within the 2011 MCR Regional Sediment Management Plan (RSMP) include: direct burial, loss of refuge for immature crab, loss of stable mature food supply for 'Harvest Ready' crab, fragmentation of fishing grounds, and any large reductions in production over time (Oregon Solutions et al., 2011). Laboratory studies have been conducted to determine mortality by direct burial of crabs by disposed material. The 2011 RSMP described the results of a laboratory study where younger crabs (age 2) had a higher mortality (47% female; 20% male) than older crabs (age 3; nearly 0%). The 2011 RSMP indicated that laboratory experiments can be difficult to extrapolate to the field, and it is expected that crab survival will be higher due to effects from surge currents and variations in sediment deposition rates (Oregon Solutions et al., 2011).

Operational considerations for minimizing impacts to Dungeness crabs include thin-layer sediment dispersal methods, and avoiding areas with large aggregations or migration routes. Commercial size and breeding adults are of the most concern, so the 2011 RSMP recommended that crab population monitoring efforts at potential disposal sites focus on these age groups (Oregon Solutions et al., 2011).

The LCSG acknowledged limitations to the currently available data as well as incomplete scientific data on crab, but felt that there is enough information to recommend proceeding with the identified disposal activities within the RSMP (Oregon Solutions et al., 2011). Benthic video surveys are being conducted in the proposed North Head Site region to observe the presence of Dungeness crab and other benthic and epibenthic organisms. In addition, there are ongoing studies to monitor Dungeness crab mortality and behavior during disposal events at a nearshore beneficial use site on the Oregon side of the MCR. These studies include video surveys of crab in response to disposal events, monitoring the deposition of the dredge material, and acoustic tagging of crab to track crab survivability and behavioral response. This information will be used to ground truth laboratory tests on the effects of dredge disposal on Dungeness crab, and will inform disposal methods and future locations, including the proposed North Head Site (U.S. Army Corps of Engineers, personal communication, September, 25, 2014).

The concerns and discussions surrounding Dungeness crab in the 2011 RSMP were focused around the proposed nearshore sites and no specific mention was made in relation to the proposed onshore sites (Oregon Solutions et al., 2011). In a 2012 Environment Assessment by the Corps for the Benson Beach site, Dungeness crab were not listed as a concern for Benson Beach onshore dredge disposal placement (U.S. Army Corps of Engineers, 2012a).

In regards to Grays Harbor, the Corps implements mitigation measures to avoid placement of dredge material in areas with high concentrations of crabs and to avoid interference with the crab fishery. The Corps follows the 1998 Revised Crab Mitigation Strategy Agreement uses best management practices to avoid, minimize, and mitigate impacts to crab (U.S. Army Corps of Engineers, 2014b).

Razor clams and other benthic species

Within the LCSG, some participants raised concerns on the effects of Razor clams (*Siliqua patula*) from dredge disposal. Concerns were related to subtidal razor clams because of their limited ability to move horizontally (Oregon Solutions et al., 2011). A study by Vavrinec, Kohn, Hall, & Romano (2007) testing adult razor clam mortality with dredge material burial showed 100% razor clam survival in sediment burial up to 12 cm (~4.7 inches). This study also indicated that limiting disposal to 12 cm every 24 hours would minimize the impacts to razor clams (Vavrinec et al., 2007). A 2009 science and policy workshop reported that intertidal razor clams on eroding beaches may benefit from onshore dredge disposal that provides additional sand for habitat (Oregon Solutions et al., 2011).

The LCSG mentioned some concern within the RSMP for a little known clam species *Tresuspajaroana*, as there is a potential occurrence of this clam in the proposed MCR nearshore disposal sites (Oregon Solutions et al., 2011).

Science and policy workshops summarized by the LCSG in the 2011 report indicated that because benthic species distributions are patchy and variable, sediment disposal would likely have a minor effect on benthic species. They did emphasize, however, that sediment should be similar in size to the naturally occurring sediment to minimize impacts (Oregon Solutions et al., 2011).

The Corps reports that effects from disposal impacts on benthic species such as polychaetes, mollusks, and enchinoderms is temporary and therefore of low concern for current disposal activities because of the invertebrates' ability to rapidly recolonize. The Corps expects the expansion in disposal material volume due to deepening of the Grays Harbor channel to have a minor additional impact (U.S. Army Corps of Engineers, 2014b).

The Corps indicated that there may be some impact to slow and immobile benthic organisms at Half Moon Bay beach and South Beach sites during sand placement for addressing a South Jetty breach risk. The Corps, however, does not expect impacts to razor clams or Dungeness crab due to low abundances in this area and the location of material placement in the high intertidal zone (U.S. Army Corps of Engineers, 2012b).

Marine fish, birds, and mammals

Not much is known about the behavioral or direct effects of sediment disposal on Washington migratory fish species such as juvenile salmon and green sturgeon. The LCSG (Oregon Solutions et al., 2011) anticipated that the potential impacts to these species are likely low, as these species can move away from the affected area. The 2011 RSMP recommends monitoring for salmon, as well as other species such as flatfish and bottom fish. Due to the variability of these populations in specific areas, dredge disposal effects may be difficult to determine. Effects on fish from turbidity in the MCR areas are not expected to be significant because the grain size of the disposal material is similar to the natural sediment material (Oregon Solutions et al., 2011).

The 2011 RSMP indicated that direct impacts to marine bird species, such as the ESA listed marbled murrelet, or other bird species such as the common murre, cormorants, and others are expected to be limited and not significant. The main concern stems from losses of prey in the foraging grounds. Dune dependent species such as the ESA listed snowy plover and streaked-horned lark may benefit from nearshore disposal placement in the MCR region (Oregon Solutions et al., 2011).

Not much is known or anticipated with regards to potential impacts of dredge disposal on marine mammals. The RSMP anticipated a low potential impact to marine mammals from dredge disposal at MCR locations, and simply recommended that disposal activities be timed to avoid gray whale migrations (Oregon Solutions et al., 2011).

Human use conflicts with disposal

Dungeness crab fishery

The uncertainty surrounding the effects of dredge disposal on Dungeness crab in shallow water has driven concerns about dredge disposal in areas heavily used by crab fishermen. Representatives within the Dungeness crab fishing industry have voiced strong concerns about the potential effects of dredge disposal from the MCR at the proposed North Head site. While the Lower Columbia Solutions Group identified the North Head site as a beneficial use area (Oregon Solutions et al., 2011), the disposal site has not been established due to concerns from representatives from the Dungeness crab industry (R. Mraz, personal communication, September 10, 2014; U.S. Army Corps of Engineers, personal communication, September 25, 2014).

The Lower Columbia Solutions Group Regional Sediment Management Plan identified Dungeness crab research and monitoring as a key priority (Oregon Solutions et al., 2011). As described in the Environmental Impacts section, there are several ongoing studies related to monitoring Dungeness crab responses to dredge disposal. The Corps will use these results to better understand what impacts disposal operations have on Dungeness crab in the ocean (U.S. Army Corps of Engineers, personal communication, September 25, 2014).

The Regional Sediment Management Plan for the MCR also included recommended management practices for reducing the risk to Dungeness crab such as: dispersing materials with a low percentage of fine sediment; dispersing sediment that is highly compatible with native sediment; avoiding “hot spots” of very high aggregations of crabs; and using thin layer dispersal practices and minimizing multiple applications over short periods of time. The LCSG encourages the use of an adaptive management plan that utilizes baseline and ongoing crab monitoring data to inform disposal in the MCR network of sites (Oregon Solutions et al., 2011).

Concerns over the impacts of dredging and dredge disposal on Dungeness crab have also influenced management decisions in Grays Harbor. The Corps utilizes mitigation measures to avoid disposal in areas with high concentrations of crab and to avoid interference with the crab fishery. To help determine which disposal site is used, the Corps conducts pre-disposal crab surveys at the two beneficial use sites South Beach and Half Moon Bay, and considers the presence of crab pots in the South Beach area (U.S. Army Corps of Engineers, 2014b).

Navigational safety

Dredge disposal has the potential to influence wave height due to mounding of the dispersed material, which can have effects on navigation safety (Oregon Solutions et al., 2011). Wave amplification has occurred historically at MCR sites, and navigational safety is a key priority in disposal site capacity management. The joint EPA/Corps Site Management and Monitoring Plan for the Lower Columbia dredging and disposal activities requires the avoidance of dredge material mounding that could cause excessive wave amplification. Results from science/policy workshops summarized in the MCR Regional Management Plan recommended that a maximum threshold of 10% wave amplification resulting from mounded disposed material over baseline conditions should not be exceeded (Oregon Solutions et al., 2011).

The EPA and the Corps, through the Site Management and Monitoring Plan and Annual Use Plans, requires bathymetry and disposal location monitoring and reporting for managing disposal activities. The Corps coordinates their Annual Use Plan with state agencies and the public, and notifies key crab fisherman who routinely fish in the disposal sites two weeks in advance of dredge disposal work (Oregon Solutions et al., 2011).

To address navigational safety at an expanded network of disposal sites (current and proposed disposal sites) for the MCR, the Regional Sediment Management Plan (Oregon Solutions et al., 2011) outlined a research and monitoring program that includes the following five strategies:

1. pre- and post-disposal bathymetric surveys,
2. assessing whether mound induced wave amplification has exceeded a maximum threshold of 10% over baseline conditions, including the use of wave models,
3. utilizing thin layer dispersal and/or respraying of reliquified sand disposal methods,
4. monitoring of shoaling in the MCR navigation channel, and
5. ongoing wind and wave modeling and monitoring.

These recommendations were created to facilitate the use of nearshore beneficial use sites, such as the proposed North Head site, while limiting the risk to navigational safety (Oregon Solutions et al., 2011). The 2011 RSMP stated that there was general agreement that onshore placement of dredge materials would avoid mounding and wave amplification. No navigational safety concerns were mentioned in the literature specific to onshore beneficial placement or flow lane disposal.

Recreation and Tourism

The 2012 Environmental Assessment produced by the Corps for the onshore Benson Beach site did indicate that there may be temporary impacts to recreational uses of Cape Disappointment State Park during dredge disposal activities. The construction site will likely include a number of restrictions and park users may be negatively impacted by construction noise. During this time, recreational activity may be reduced and there may be an impact on tourism income to nearby communities. The Corps does state that this impact would be temporary and also indicates that recreation and tourism would benefit in the long-term by reducing long-term erosion impacts (U.S. Army Corps of Engineers, 2012a).

Permitting requirements

The management of dredge disposal is important for human and environmental health and safety in Washington's waters. Between 2000 and 2012, 21.2 million cubic yards of dredged material were disposed at the Grays Harbor and Willapa Bay disposal sites (Dredged Material Management Program, 2012), and about 48.6 million cubic yards of dredged material were disposed at the MCR sites (U.S. Army Corps of Engineers, 2014a).

State and federal agencies work together to evaluate and manage dredge material disposal. Disposal sites in Washington waters are designated by one of three agencies: the EPA, Corps, or WDNR. The specific process for disposal permits and authorizations varies slightly depending on which agency designated the site and who the project proponent is (Corps or private entity). However, environmental review for water quality, physical effects, and species consultations are always performed, regardless of the disposal project.

To help coordinate the various agencies involved in managing, permitting, and authorizing disposal sites, two interagency teams have been developed in Washington to evaluate sediment suitability for in-water disposal and help streamline disposal regulations. The Washington Dredged Material Management Program (DMMP) includes experts from the Corps, U.S. Environmental Protection Agency (EPA), Ecology, and DNR and reviews dredge projects within the Corps Seattle District (Dredged Material Management Office, 2013). The Portland Sediment Evaluation team, which is similar to the DMMP, evaluates and coordinates sites at the MCR (L. Inouye, personal communication, October 9, 2014). These teams require sediment evaluation which generally includes a site history analysis, and possibly chemical and biological testing of the material to be dredged. Sediment evaluation requirements must be met prior to obtaining any permits (Dredged Material Management Office, 2013).

Regardless of who designates the disposal site, dredging and disposal operations require approval from various federal, state, and local authorities. The federal permits include Rivers and Harbors Act Section 10 permits and Water Quality Act Section 404 permits issued through the Corps. An Endangered Species Act Section 7 consultation with the NOAA National Marine Fisheries Service and possibly the U.S. Fish and Wildlife Service is also required. For dredge disposal from maintenance dredging activities performed by the Corps, such as for the Grays Harbor navigation channel and MCR, the Corps does not issue itself permits, but public notices, federal consultations, and all state requirements are complied with (Dredged Material Management Office, 2013).

Several state agencies play a regulatory and policy role in dredge disposal. In addition to participating on the DMMP and the Portland Sediment Evaluation Team, Ecology issues a 401 Water Quality Certification, a Coastal Zone Management Act consistency determination, and reviews any relevant local permits that may apply under the local Shoreline Master Program (SMP). The Washington Department of Fish and Wildlife (WDFW) may require a Hydraulic Permit Approval. The WDNR requires project proponents to obtain a disposal site use authorization prior to disposal, if utilizing a WDNR authorized site. Local governments, through their local SMP, may require a Shoreline Substantial Development Permit, Exemption Letter, or a Conditional Use Permit (Dredged Material Management Office, 2013; Office of the Governor, 2006).

Once all appropriate permits and authorizations are issued, the Corps requires submission of a dredging and disposal quality assurance plan. The Corps may hold a pre-dredge conference with the applicant and other regulatory agencies to review the final disposal plans (Dredged Material Management Office, 2013). For the Corps' dredging operations at the MCR, Ecology and the EPA require the Corps to submit their Annual Use Plan prior to disposal (L. Randall, personal communication, October 14, 2014). Regulatory agencies must issue all required permits and authorizations before dredging and disposal begins (Dredged Material Management Office, 2013).

Flow lane disposal permitting is slightly different from other disposal methods. Ecology does require 401 Water Quality certifications for flow lanes. Other required permits depend upon whether or not it is a Corps project or a port/private operation (L. Randall, personal communication, October, 14, 2014). In either circumstance, project-specific analysis is mandatory for flow lane disposal and agencies must approve of this alternative under the NEPA/SEPA process (Dredged Material Management Office, 2013). Consultation with the DMMP or Portland Sediment Evaluation Team is also required, and may include a turbidity simulation for the flow lane disposal (Dredged Material Management Office, 2013). Project proponents can be responsible for monitoring for increases in turbidity outside of an established mixing zone (R. Chaffee, personal communication, October 1, 2014).

Dredge disposal on tribal land also has a tribal authority nexus. In the MSP Study Area, the Corps works with the Quileute Tribe for dredging and disposal in the Quilleyute River at La Push. The tribe issues a yearly permit to the Corps to authorize disposal locations (Quileute Tribe, 2014).

Water quality standards

Water quality for public health and environmental protection is a strong concern within Washington. In-water disposal of dredged material must adhere to federal and state water quality standards. These water quality parameters include dissolved oxygen, turbidity, and contaminants [WAC-173-201(A)]. The DMMP and Portland Sediment Evaluation Team also have specific standards related to testing for contaminated dredge material. In-water sediment disposal may also be required to meet the Washington State Sediment Management Standards (Dredged Material Management Office, 2013).

Site selection

Selecting and managing disposal sites is a complex process with many human use and environmental considerations. As described above, several agencies are involved in designating and managing disposal sites, and each agency has its own authority and considerations. For example, DNR uses a number of environmental considerations when selecting and authorizing disposal sites, such as avoiding unique habitats, utilizing sites with similar substrate to that being disposed, protecting known fish nursery, migration, and harvest areas, and protecting aquaculture installations [WAC 332-30-166]. Despite differences in agency authority and mandates, human use and environmental concerns are often addressed, although occasionally through different mechanisms depending upon the relevant authorities.

Future trends

Grays Harbor

The Port of Grays Harbor requested that the Corps deepen the navigation channel from -36 feet MLLW to the legislatively authorized depth of -38 feet MLLW. This is because the current depth of -36 feet MLLW narrows the tidal window for deep-draft vessels to call to port. As a result, vessels are often partially loaded or experience tidal delays (U.S. Army Corps of Engineers, 2014b). In 2015, the Corps approved construction, and construction began in October 2016. It is not the intention of the MSP to address deepening activities in the Grays Harbor navigation channel. However, the MSP may play a role in any suggested changes to dredge disposal sites within the Study Area.

To accommodate the additional amount of dredged material from the 2 foot deepening of the Grays Harbor channel, the Corps proposes a one-time 1,000 foot north-northwestern shift in the Point Chehalis open-water disposal site. Dredged material from the initial deepening activities would be placed within the shifted disposal site. This proposed one-time shift is intended to take advantage of deeper water and more favorable hydrodynamics for the additional capacity needed during the channel deepening construction year. About 1,972,000 additional dredged cubic yards is estimated for the initial channel deepening, resulting in about 4,062,000 cubic yards of total dredged material for the construction year. Dredge material from subsequent annual maintenance dredging would be placed in the currently designated Point Chehalis DNR DMMP in-water site (U.S. Army Corps of Engineers, 2014b).

The DNR is also considering shifting the South Jetty disposal site slightly north in order to keep it within the scour channel (C. Barton, personal communication, October 27, 2014).

Another potential small change in dredge disposal locations within the Grays Harbor area is related to the actions to control erosion and reduced the risk of a breach at the east end of the South Jetty between South Beach (Pacific Ocean) and Half Moon Bay. A breach first occurred during a winter storm at this location in 1993. Since then, the Corps has maintained a land connection between the shoreline and the South Jetty by placing sand on the dune between Half Moon Bay and South beach. This sand placement is performed whenever certain threshold criteria are triggered. The Corps monitors this area, and when it is determined that sand must be added to avoid a breach, the material is taken either from the Point Chehalis revetment extension mitigation site (U.S. Army Corps of Engineers, 2012b) or sand is purchased for the addition (U.S. Army Corps of Engineers, personal communication, September 29, 2014).

In 2012, the Corps proposed a long-term management plan to address the ongoing risk of a breach at the South Jetty. This included building a modified diffraction structure at the eastern terminus to the South Jetty and continuing to place sand on the dune area between Half Moon Bay and South Beach similar to the current activities performed by the Corps. If this proposed alternative moves forward, the location of dredge disposal will change slightly within the Half Moon Bay and South Beach location relative to current activities (U.S. Army Corps of Engineers, 2012b). The proposed long-term management strategy for the South Jetty is still under review.

Mouth of Columbia River

In the draft 2011 Regional Sediment Management Plan for the Mouth of the Columbia River, the LCSG identified two nearshore beneficial use sites for dredge disposal that are within the Washington MSP Study Area (Oregon Solutions et al., 2011). The first, Benson Beach, was used in 2010 as an onshore demonstration project (Map 52) (see Summary of History and Current Uses: Mouth of Columbia River). Benson Beach is currently permitted by Ecology for use by the Corps for dredge disposal, yet it has not been used since the 2010 demonstration project. Onshore placement of dredge material requires additional equipment, logistics, and time compared to traditional bottom-dump disposal methods. These considerations increase the cost of disposal (Oregon Solutions et al., 2011). Safety concerns for the dredge operators were also raised during the 2010 demonstration.

The Corps operates under a least cost alternative policy. Because of the increased cost associated with onshore placement, an outside source must provide the incremental increased cost incurred for using the Benson Beach site (U.S. Army Corps of Engineers, 2012a). The State of Washington provided $1.69 million in addition to the Corps $1.8 million for the 2010 demonstration project (Oregon Solutions et al., 2011). The future use of Benson Beach as an on-shore beneficial disposal site is dependent upon additional funding (U.S. Army Corps of Engineers, 2012a).

The second site, named the North Head Nearshore Site, is a nearshore subtidal site located generally north of the North Jetty and off of North Head in Cape Disappointment State Park. This 2011 RSM identified this site for the potential to minimize erosion at Benson Beach and Peacock Spit and to contribute to beach accretion (Oregon Solutions et al., 2011). The Dungeness crab fishery historically avoided this area and initially identified it as a potentially acceptable beneficial dredge disposal site. However, the crabbing fleet now uses the North Head nearshore area frequently. Therefore, concerns on the effects to the Dungeness crab fishery and navigational safety from disposal material mounding has led to strong opposition from some for the use of this site for dredge disposal (U.S. Army Corps of Engineers, personal communication, September 25, 2014; R. Mraz, personal communication, September 10, 2014) (See Human use conflicts and Environmental impacts sections). Several studies are currently being conducted in the North Head nearshore area.

In the event the Corps decides to pursue adding a North Head site to the sediment management network of disposal sites at the MCR, the site would need to go through a designation and permitting process. The site would be designated for use either by the Corps through their Section 404 authority, or the EPA. As a part of the permitting process, the lead agency would conduct a NEPA process including environmental studies and consultations with NOAA National Marine Fisheries Service. The Corps would then apply for an Ecology 401 Water Quality Certification. After thorough review, Ecology may authorize the use of this site by issuing a 401 certification and a Coastal Zone Management Act consistency determination (L. Randall, personal communication, October 14, 2014).

Small Ports

Small ports are likely to continue to use a mix of flow lanes, small scale beneficial use sites, and DNR authorized sites for dredge material disposal and no significant alterations are anticipated. Expanded activities include the possible addition of a few flow lanes within Willapa Bay (R. Chaffee, personal communication, October 1, 2014).

With regards to future trends in funding, it is difficult to predict what the future federal funding will be for small ports within the Study Area. The 2014 Water Resources Reform and Development Act may result in a certain portion of the Harbors Maintenance Trust Fund to be allocated toward small ports, although it could be a few years before this is implemented (U.S. Army Corps of Engineers, personal communication, September, 2014). It is very likely that small ports will continue to seek federal funds to keep their ports open and accessible due to their economic and social importance to the coastal communities of Washington.

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2.10.4 Marine Product Extraction

A potential new use of Washington's Pacific coast is the extraction of marine organisms for commercial industries[1] such as cosmetic, pharmaceutical, and biomedical research.

Summary of history and current use

Marine product extraction is the practice of harvesting marine plants and animals to develop non-food related goods. Examples of products derived from marine organisms around the world include anti-viral, anti-cancer, and anti-tumor agents used in medical treatments, an anti-inflammatory agent used in a cosmetic skin cream, chemicals used in biomedical and cell biology research, and fatty amino acids in nutritional supplements (Arrieta, Arnaud-Haond, & Duarte, 2010; Baerga-Ortiz, 2009; Bruckner, 2002; Pomponi, 1999).

Researchers, universities, government agencies, and private companies use marine bioprospecting to search for compounds that can be used for human health and well-being products (Bruckner, 2002). Marine bioprospecting methods for compound identification include SCUBA diving, manned submersible vehicles, remotely operated vehicles, and collection of organisms from intertidal areas (Arrieta et al., 2010; Pomponi, 1999).

Once a potential compound has been identified, it must go through a series of product testing and clinical trials before it can be released on the market. Identifying compounds, testing them, performing clinical trials, and selling products commercially requires various quantities of the target organism. Often compounds discovered within marine organisms are only available in small amounts per organism. Therefore, it may require harvesting vast amounts to get the required quantity for testing and market availability. Alternatives to mass wild harvesting are the use of aquaculture or the use of biotechnology to synthesize the newly discovered compounds in a lab (Arrieta et al., 2010; Pomponi, 1999).

For each newly discovered product, the potential intensity of harvest from natural populations in the ocean will depend upon the demand for the target product as well as the ability to replicate it in the lab or through aquaculture. In the case of DNA sequence discovery, a onetime extraction may be all that is needed, as DNR replication techniques can be used in the lab. For natural products, however, additional and perhaps extensive collections may be required (Arrieta et al., 2010). Methods for supplying natural products are influenced by the availability and reproductive biology of the host organism, the quantity of the target compound per biomass unit, the complexity of the biosynthetic pathway, and suitable environmental conditions for biochemical synthesis (Pomponi, 1999).

Several target products discovered in marine organisms have been successfully synthesized using biotechnology. However, many of these processes are quite complex and may not be cost effective for industrial scale production (Baerga-Ortiz, 2009; Pomponi, 1999). There is ongoing research to increase the understanding of biosynthetic pathways to sustainably and cost effectively supply marine extracted chemicals for pharmaceutical treatments (Baerga-Ortiz, 2009).

Land-based and in-the-sea aquaculture has also been used to grow host organisms. For example, the mangrove sea squirt, *Ecteinascidia turbinata*, from which an anti-tumor compound has been successfully isolated, has been cultured on a commercial scale (Arrieta et al., 2010; Pomponi, 1999). A deep-water sponge in New Zealand (*Lissodendoryx* sp.), identified for another anti-tumor compound, has been successfully cultured in shallow water while maintaining the anti-tumor compound. This indicates the

[1] Marine product extraction, as discussed here, does not include any extraction or harvest performed by the tribes.

potential for shallow-water culture of deep-water sponges. However, other target compounds from deep-water host organisms may require the specific pressure, temperature, and other deep-water conditions to form, so the use of aquaculture to supply target compounds from deep-water organisms may be limited (Pomponi, 1999).

Wild harvest of marine organisms to meet the quantity demands for clinical testing and commercial supply may not be sustainable for many organisms. Monitoring and evaluation of harvest impacts can help determine the sustainability of wild collection, before large scale harvest commences. For example, a feasibility survey found that the New Zealand deep-water sponge could only sustain small quantities of harvest, despite rapid recovery from extraction by dredging (Arrieta et al., 2010). Sustainable harvest of marine organisms for marine product extraction is, however, possible for some species. A Gorgonian coral in the Bahamas harvested for an anti-inflammatory compound used in a cosmetic skin cream has been harvested for over 15 years by utilizing a sustainable harvest management plan (Arrieta et al., 2010; Bruckner, 2002). Sustainability remains a key issue for marine product extraction (Arrieta et al., 2010; Bruckner, 2002; Pomponi, 1999).

Potential use compatibilities

Marine Protected Areas (MPAs) and marine product extraction have the potential to be compatible uses. MPAs have been recognized as a way to protect marine genetic reserves and be sources for future discoveries (Arrieta et al., 2010). The ecological impact from the initial phase of marine bioprospecting is likely to be minimal, due to the limited amount of harvest required to identify a compound or perform DNA sequencing. It is the potential for more intense harvest for clinical trials and commercial supply that sparks concerns over the sustainability and habitat impacts of marine product extraction. Conservation measures are recommended for the sustainability of marine product extraction (Arrieta et al., 2010; Bruckner, 2002). Possible measures include harvesting feasibility studies (Pomponi, 1999), monitoring (Bruckner, 2002), sustainable collection methods, and export regulations (Arrieta et al., 2010).

Potential use conflicts

No information was found on conflicting uses, with the exception of potential environmental conflicts in cases of unsustainable or habitat altering harvest practices (Arrieta et al., 2010; Bruckner, 2002; Pomponi, 1999). Spatial conflicts with other uses are difficult to forecast because extraction may be very temporary (initial bioprospecting) or a continued, large scale commercial harvest. Even in circumstances where a sustained harvest were to occur, it is difficult to generalize the conflicts as it would depend upon the organism harvested, the method, intensity, and frequency of harvest, and other factors.

Permitting marine product extraction

The Washington Department of Fish and Wildlife (WDFW) has the permitting authority for scientific exploration and harvesting of marine organisms, including plants and animals. State regulations require a scientific collection permit for collection of organisms for research or education (WAC 220-20-045). This permit would likely apply to researchers or universities engaging in bioprospecting (discovery and sampling) of marine organisms.

The harvest of marine organisms for commercial activity (selling the organism) must also be permitted through WDFW. Extracting marine organisms to sell to processors, research labs, etc, would fall under a harvesting permit. If there is no established commercial fishery for the target organism, the WDFW director could establish an emerging commercial fishery, which would include a permit process. This would be either a trial fishery or an experimental fishery permit (M. Culver, personal communication, November 10, 2014). Trial fisheries, by statute, cannot be limited; experimental fisheries are limited and require WDFW to convene an advisory board with representatives from the fishing industry to make recommendations to the WDFW director for fishery management (RCW 77.80.160). Within five years, the WDFW director would submit a report to the WA senate and house with recommendations relating to the establishment of a permanent commercial fishery license, fee, and/or limited harvest program (RCW 77.70.180).

WDFW has the authority to regulate harvest in both the state and federal waters off of WA's coast and to permit the transport and/or sale of organisms harvested in state or federal waters into WA. States have the authority to manage the harvest of marine organisms in federal waters in the absence of a federal management plan for the target species (Magnuson-Stevens Act of 2006). If there was an interest for marine product extraction in federal waters off the WA coast, WDFW would likely have a role relative to permitting and management.

Under RCW 79.105 and WAC 332-30, the Washington State Department of Natural Resources (DNR) has the authority to manage 2.6 million acres of state-owned aquatic lands as a public trust. The statute requires DNR to manage these lands to promote uses and protect resources of statewide value. Any person or organization interested in removing valuable materials from state-owned aquatic lands must apply to the DNR for a use authorization, including the extraction of marine organisms for commercial products.

Potential along Washington's Pacific coast

Globally, new discoveries of unique chemicals and DNA sequences from marine organisms are occurring at a rapid pace. The rate of new natural products reported from marine organisms is growing at a rate of 4% per year, which is faster than the rate of species discovery. About 18,000 natural products have been described from marine organisms since the 1950s (Arrieta et al., 2010). Marine organisms from which new products have been discovered include sponges, microalgae, coral, deep-sea hydrothermal vent bacterium, bioluminescent jellyfish, red algae, a snail, and a sea hare (Bruckner, 2002; Pomponi, 1999). The potential for novel chemicals from marine organisms is estimated to be about 300 to 500 times higher than discovery from terrestrial sources (Arrieta et al., 2010; Bruckner, 2002). Marine product extraction presents a considerable economic and business opportunity; the marine biotechnology industry is currently a multibillion dollar industry and growing (Arrieta et al., 2010; Bruckner, 2002).

It is impossible to know when and where a new compound may be discovered, but it is predicted that high biodiversity habitats such as coral reefs and seamounts, and extreme habitats such as hydrothermal vents and polar habitats have the greatest economic potential for new chemical discovery (Arrieta et al., 2010). The potential for marine product extraction along the WA Pacific coast is unclear. Based on the literature, it does not seem likely that the WA coast is a primary target for marine bioprospecting. However, WA does have unique environments including hydrothermal vents, seamounts, and deep sea corals. Therefore, as new marine species are discovered and technology expands the depths of the ocean to be explored, it is entirely possible that novel chemicals and DNA sequences could be discovered within Plan waters.

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2.10.5 Mining

A potential new use of Washington's Pacific coast is mining within marine waters for sand and gravel as well as gas hydrates. This chapter provides context for sand/gravel and gas hydrate mining operations, environmental impacts, use conflicts, and future trends in Washington. Gold mining, which is a current use within the MSP Study Area, is covered in Section 2.6 Recreation and Tourism.

Sand and gravel mining

Sand and gravel are mined more than any other material in the world, and worldwide demand is increasing. Declining land-based sand and gravel resources has shifted mining for these resources into marine waters. Globally, marine sand and gravel are used mainly for construction and land reclamation (Peduzzi, 2014).

In the United States, marine sand mining is used to supply material for beach nourishment along the Atlantic and Gulf of Mexico coasts. Several states mine marine sand for beach nourishment projects and some have partnered with the Bureau of Ocean Energy Management (BOEM) to extract sand from offshore sites in federal waters. State and local governments use this sand to renourish public beaches, restore coastal habitats, and build nature-based infrastructure to protect against coastal storms and erosion. In the United States, demand for marine sand is increasing due to coastal erosion, increasing coastal storms, and sea level rise. BOEM continues to work with state and local partners and is updating evaluations for sand resources within BOEM lease blocks (Bureau of Ocean Energy Management, 2014).

The majority of in-water sand and gravel mining in Washington is currently limited to rivers. Much of the sand that is removed in rivers is for navigation or flood control, very little mining is currently performed for the pure purpose of obtaining and selling sand (M. Rechner, personal communication, November 20, 2014). A couple of sand mining companies mine sand on the WA side of the Columbia River to sell for construction and other uses (L. Randall, personal communication, November 25, 2014).

The dune restoration project at Shoalwater Bay is a similar activity to sand mining activities on the Atlantic and Gulf coasts for beach nourishment. The Army Corps of Engineers dredged (mined) sand within Willapa Bay, and placed the material to reconstruct eroding dunes at Shoalwater Bay. For more information, see Shoalwater Bay project in the Section 2.10.3 Dredging and Dredge Disposal Chapter.

A localized sand removal activity within the MSP Study Area is for maintenance of public beach access and subsequent sand use by cranberry growers. The Washington State Parks and Recreation Commission (Parks) maintains public beach access along ocean beaches within the Washington State Seashore Conservation Area by occasionally removing accreted sand at access points. Parks is authorized to sell permits to cranberry growers to use this sand within their bogs. This use of sand is allowed if found by Parks to be reasonable, and not generally harmful or destructive to the character of the land (RCW 79A.05.630). This activity is currently exercised by a handful of growers in the Long Beach area. The cranberry growers use sand to improve productivity within their nearby cranberry bogs. The volume of sand from the Seashore Conservation Area used for this purpose is relatively small, and growers often find acquiring the sand from other sources to be an easier option. This use is not anticipated to expand in the near future (L. Lantz, personal communication, December 11, 2014).

Marine sand and gravel mining equipment and infrastructure

The equipment and infrastructure for sand and gravel mining is very similar to navigation dredging and disposal. Mining for sand and gravel in marine water is generally performed with a trailing suction hopper dredge or a cutterhead dredge. When trailing suction hopper dredges are used to mine sand for beach nourishment, the material is typically stored within hoppers on the ship and transported to a pump-out station near the placement site. The dredge is then hooked up to a pipeline at a pump-out station and material is pumped to shore via pipeline laid on the seabed. Occasionally for beach renourishment projects, the material is placed at a nearshore temporary holding and rehandling site near the nourishment project site which is then dredged again and transported by pipeline. Temporary storage and nearshore rehandling areas are becoming more frequently used on the Gulf and East coast, especially when using offshore sites long distances from the placement sites (Michel, Bejarano, Peterson, & Voss, 2013).

Cutterhead dredges are typically used closer to shore, and the dredged material is transferred directly from the dredge to the placement site via a pipeline. Cutterhead dredges often require barges, multiple anchors, support boats, survey boats, and crew boats. Pump-out of the material through a pipeline requires a long list of equipment, including but not limited to tugs, buoys, cranes, support crew boats, and floating and submerged pipelines. Transport pipelines are assembled using barges with cranes, and multiple tugs position the line before it is flooded into place on the seafloor. These pipelines are temporary structures which can be repositioned and disassembled once the project is complete (Michel et al., 2013).

Marine mining equipment also can have dump valves on the intake pipe. Sand and gravel mining activities target a specific size of material; should the dredge encounter unsuitable material, the dump valves are used to instantly dump the material overboard before it enters the hopper (Tomlinson et al., 2007). The ships may also have sorting and screening equipment to release unwanted fine sediments (Michel et al., 2013). Sand and gravel mining activities to sell for land-based purposes also require shore-based facilities for storage, handling, and distributing the material.

Potential use benefits and compatibilities

Sand and gravel mining is a compatible use with beach renourishment and coastal protection projects. Depending upon the location, amount and type of material needed for the coastal defense project, mining may be the most practical and cost effective alternative to provide the needed material. Sea level rise and climate change (including increased frequency of coastal storms) may increase the need for beach and dune renourishment to protect recreational beaches and coastal infrastructure. The dune reconstruction at Shoalwater Bay is a good example of a current sand mining project to protect coastal infrastructure and intertidal habitat for tribal shellfish beds from coastal flooding and storms (U.S. Army Corps of Engineers, 2009) (See Dredge Disposal Chapter).

No information was found in the literature on compatible ocean uses with sand and gravel mining for upland purposes (construction, road maintenance, etc).

[This section still to be completed.]

Environmental concerns

No literature was found regarding sand and gravel mining (dredging) impacts for offshore areas in Washington, as it is not a current use. The summary below describes the available literature for observed and potential environmental impacts from offshore sand and gravel mining along the Atlantic and Gulf coasts, as well as general environmental considerations from navigation dredging in Grays Harbor.

Benthic species and habitats

Immobile and slow moving benthic species could be directly removed by sand and gravel mining (dredging) through entrainment into the suction dredge. The amount of time for benthic species recovery is variable. Studies on the Atlantic and Gulf coasts report that biomass and abundance recover times range from 3 months to 2.5 years after offshore dredging. Species diversity recovery can take more than 3-5 years after offshore dredging. Monitoring at U.S. sand mining sites has not been long enough to determine times for complete community recovery (Michel et al., 2013). For navigation dredging at estuarine sites in Washington, the Corps reports benthic invertebrate recovery of juvenile salmon prey at sites at the Ports of Tacoma and Seattle within months of the dredging activity (U.S. Army Corps of Engineers, 2014). Studies from the East coast report that recolonization of the dredged areas is similar to successional colonization from other disturbances (Michel et al., 2013).

Benthic organisms may also be directly impacted by pipelines transmitting sand. Pipelines can directly displace and crush benthic invertebrates, and this impact may be increased by movement of the pipeline during storms if it is not securely positioned. Hard bottom habitats are expected to experience the greatest impacts from pipelines, while soft-bottom habitats are expected to quickly recover after pipeline removal (Michel et al., 2013).

Mining can create pits along the seafloor. Observations in South Carolina have shown that finer material such as mud can accumulate in these pits, which can lead to changes in the benthic community composition (Michel et al., 2013). Levels of oxygen could also be reduced within these pits. Recommended mitigation measures to assist in rapid recovery of benthic habitats have included rotational dredging, dredging areas expected to rapidly refill, avoid creating deep pits, and leaving some areas undredged. These methods have yet to be tested. (Michel et al., 2013).

Deposition of sediments on the seafloor and turbidity may also affect benthic invertebrates. Turbidity and deposition of finer materials (silt, mud) can be caused by the drill head, but also by fine materials washed overboard. Studies from dredging on the outer continental shelf on the East coast indicate that turbidity concerns are generally low when mining clean sands. In addition, dynamic, offshore habitats are generally acclimated to natural sedimentation. Turbidity and sedimentation effects are of greatest concern to coral reef and hard-bottom habitats and spawning areas (Michel et al., 2013).

It is unclear whether benthic community composition changes will be beneficial or detrimental to predatory species such as fish and crabs. These effects will depend upon the specific predator-prey relationship, species life histories, and timing of the dredging activities (Michel et al., 2013).

The impacts of noise on benthic invertebrates remain largely unknown (Michel et al., 2013).

Fishes and other mobile species

Sand and gravel mining (dredging) may directly or indirectly impact bottom and pelagic fishes and other mobile species such as crabs. South Atlantic Fishery Management Council, researchers, and other institutions have expressed concerns about the effects of offshore dredging to the ecological services of sand shoals to fishery resources (Michel et al., 2013). Adult fish and mobile bottom dwelling fish species are expected to be able to swim away from the dredging activities. However, higher risks to fishes may be associated with the smothering of eggs on spawning grounds, or the entrainment of eggs, juveniles, or benthic species by the suction dredge. It is also possible that pelagic eggs could be impacted by turbidity. Possible indirect impacts include alteration of prey availability for bottom fish as well as loss of habitat (Michel et al., 2013).

There are many concerns surrounding the impacts to fish and other mobile species from offshore sand and gravel mining, yet several data gaps exist regarding this topic. Most of the entrainment rates for fishes and mobile invertebrates have been assessed for shallow-water and estuarine dredging activities. In a literature review summarized by Michel et al. (2013), Dungeness crab entrainment rates by hopper suction dredges in estuarine and river settings were reported to range from 0.040 to 0.592 adult crabs per cubic yard of dredged material, with juvenile crabs entrained at 0.32 to 10.78 crabs per cubic yard. Mortality was reported to increase with increasing crab size from 5% for smaller crabs (7-l0 mm) to 86% for larger crabs (>75 mm) (Michel et al., 2013). In Grays Harbor, A Dredge Impact Model is used by the Corps to estimate the number of Dungeness crab losses for navigational dredging (U.S. Army Corps of Engineers, 2014). However, it is unknown what the entrainment and subsequent survival rates for Dungeness crab or fish would be at an offshore sand borrow site. Existing information from other locations suggest that eggs deposited on the seafloor and bottom-dwelling fish are the most sensitive to entrainment. Entrainment rates and the subsequent impact on fishery resources remains a data gap (Michel et al., 2013).

In Washington, dredging could entrain lingcod, flatfish, and possibly rockfish. However, the likelihood and rates of entrainment will depend upon the mining location and life history of the fish species (U.S. Army Corps of Engineers, 2014).

The redeposition of sediment from sand and gravel mining activities could pose a risk to smothering eggs on bottom-dwelling fish spawning grounds and burial of crabs. While species with eggs attached to the seafloor are considered to be sensitive to this potential impact, the specific quantitative effects are unknown. Bottom-dwelling species are expected to have some tolerance to natural sedimentation (Michel et al., 2013). Spawning could be disrupted if spawning periods overlap with dredging operations (Tomlinson et al., 2007). Seasonal work windows have been recommended for mining in the United Kingdom, but their effectiveness in reducing impacts has not been confirmed. Early life stages of fish that use hard-bottom habitats also may potentially be impacted by sediment deposition over those habitats. Site specific buffers around hard-bottom habitats are used for offshore sand mining along the East coast to reduce impacts (Michel et al., 2013).

Water quality may decrease within deep dredge pits where water exchange is reduced and oxygen levels are reduced. This may stress organisms unable to move to more oxygenated locations. Noise from dredging operations may also have a temporary and limited impact to fish populations. Potential effects from noise could include changes in behavior and physiological (loss of hearing) damage (Michel et al., 2013). A study in the North Sea found that fish migrations to spawning areas were altered during dredge activity (Tomlinson et al., 2007). Specific effects from noise will be species dependent, and more research is needed to assess the hearing abilities of fishes at various life stages (Michel et al., 2013).

Birds

No direct information was found assessing impacts from East coast offshore sand mining activities. Potential impacts predicted to have the largest effects include indirect impacts to foraging seabirds from repeated dredging of sand shoals, flight path avoidance, and flock disturbance if dredging or associated navigation occurs near areas with dense flocks. It is unknown to what extent any of these impacts would have on seabirds (Michel et al., 2013). The Environmental Impact Statement for Grays Harbor navigation dredging suggests that dredge vessels and turbidity may temporarily displace foraging seabirds and waterfowl (U.S. Army Corps of Engineers, 2014). Offshore sand and gravel mining (dredging) effects on seabirds represents a large data gap (Michel et al., 2013).

Marine Mammals

Marine mammals could potentially be impacted by sand and gravel mining operations (dredging) through pressures such as vessel interactions (vessel strikes), noise, and water quality. Vessel strikes can cause injury or mortality to whales, and therefore mining may pose some increased risk to whales.

However, dredging vessels are often slow moving, and East coast dredging operations have mitigation measures to reduce risk to marine mammals. There have been no reports of marine mammal strikes from dredging or support vessels during dredging operations (Michel et al., 2013).

Noise from dredging and vessel operations has the potential to alter marine mammal behavior. Specific effects and severity will depend upon the actual noise generated by the dredge and the marine mammal species. There are few studies which document the reactions of marine mammals to dredging. Direct injury to marine mammals from the sound produced from offshore dredging operations is estimated to be unlikely based on the NOAA noise threshold criteria, although behavior disturbance and harassment are possible. Potential impacts to marine mammals are assessed for individual projects through Section 7 consultations (Michel et al., 2013).

It is unknown if or how marine mammals are impacted through disturbance of bottom habitats, turbidity, and deposition of fines onto the seafloor from dredging (Michel et al., 2013).

Sea turtles

The main concern for East coast offshore dredging is the entrainment and mortality of sea turtles. Loggerheads, Kemp's ridley, and Green sea turtles are considered to have the highest risk of entrainment due to their benthic foraging habitat preferences. Several mitigation measures have been developed to reduce entrainment and mortality of sea turtles (Michel et al., 2013). There is little to no information on other potential impacts, such as alteration of benthic habitat, noise, turbidity, vessel strikes, and increased sediment deposition. A review of biological impacts from offshore dredging indicated that most impacts will likely be specific to the sea turtle species life histories, prey and habitat preferences, and behaviors (Michel et al., 2013).

Ecosystem effects

As mentioned above, sand and gravel mining directly impact bottom habitats and benthic species. It remains uncertain, however, to what degree these impacts have on trophic systems and ecological interactions. Ecosystem impacts are difficult to measure. Food web and other ecosystem models have been used to try to examine direct and indirect impacts of sand mining in marine systems, yet there is currently high uncertainty based on limited information (Michel et al., 2013).

Another area of uncertainty is the potential cumulative impacts from sand and gravel mining and current and historical fishing activities, particularly the bottom-disturbing fisheries. The impacts from bottom-disturbing fishing can serve as a proxy for examining the potential ecosystem impact from sand and gravel mining, although a few key differences exist. These differences include intensity of the activity (sand mining may have a greater direct disturbance to the bottom habitat as compared to bottom disturbance fishing) and spatial extent of the activity (sand mining will likely be located at fewer sites and smaller in scale than bottom disturbance fishing) (Michel et al., 2013).

Ecosystem and food chain effects from sand and gravel mining activities remain a data gap of high interest to ecosystem based management, fishery commissions, and other interested groups (Michel et al., 2013).

Potential use conflicts

Sand and gravel mining activities have the potential to conflict with current and potential new uses in Washington's MSP Study Area. Conflicts with commercial and recreational fisheries have been studied for sand and gravel mining activities along the East coast and the United Kingdom. Based on literature reviews and case studies in Florida, common spatial conflicts between commercial and recreational fisheries and sand and gravel mining include: loss of fishing gear (particularly crab pots), changes to navigation routes, reduced access to fishing grounds, and increased boat traffic (Tomlinson et al., 2007).

The loss and damage of gear, particularly fixed gear such as crab pots, due to dredging operations is a contentious issue voiced by fisherman in the U.S. Gear can be directly damaged, or buoys can be severed, interfering with equipment retrieval. This may lead to economic impacts to the fishermen for the cost of replacement gear and loss of catch (Tomlinson et al., 2007).

In some locations, fishermen have reported concerns about disruptions to their navigation routes. Dredging activities and equipment may require fishermen to alter navigation routes to their traditional fishing grounds, depending upon the material borrow and placement sites. This may increase time and money for the fisherman, including increased fuel costs. Dredging operations may also directly restrict access or displace fisherman from traditional fishing grounds. This conflict will depend upon the location, season, and longevity of the dredging (Tomlinson et al., 2007).

Sand and gravel mining activities may also increase boat traffic, which can lead to increased risk of collisions or increased inconveniences to fishermen avoiding large dredging vessels. Effective communication and standard operating procedures regulated by the U.S. Coast Guard can mitigate these risks. However, shrimp fishermen in Lee County, Florida have reported loss of catch due to avoiding dredge vessels while towing their nets (Tomlinson et al., 2007).

Fishermen in Florida (sand mining) and the United Kingdom (gravel mining) have also expressed concerns related to dredging impacts on fish and crab ecology and how it may influence the stock availability and catch. There is an established history of conflict between the sole and brown crab fisheries with the gravel mining operations at Hastings Shingle Bank. For example, the Hastings fleet in the United Kingdom, which is a net fishery for sole, estimates that the sole stock has been reduced from 16,000 tons to 2,000 tons since gravel dredging was undertaken at the Hastings Shingle Bank. As of 2007, it is unclear as to the exact dredging impacting mechanism is for this stock reduction (Tomlinson et al., 2007).

Case studies indicate that the severity of these spatial conflicts vary between project locations and specific fisheries. For example, in Brevard County, Florida, concerns about dredging traffic interfering with fishing navigation routes were expressed by the finfish industry but not by the shrimp industry (Tomlinson et al., 2007). The location of the borrow sites, placement sites, and dredging traffic routes with respect to specific fishing grounds and access routes will significantly influence the level of potential conflict between sand/gravel mining and fisheries.

Poor communication can also increase conflict during dredging operations. Fishermen in Lee and Collier Counties in Florida have reported increased gear loss and navigation issues due to poor communication about dredge and support vessel traffic locations (Tomlinson et al., 2007).

Sand and gravel mining operations may also pose potential conflicts with other current and future uses, particularly those with permanent or semi-permanent infrastructure. Sand and gravel mining is generally not suitable in areas with offshore oil and gas infrastructure, including platforms and pipelines (Michel et al., 2013), and therefore we can predict that other similar infrastructure, such as for marine renewable energy or methane hydrate mining will also not be compatible. Dredging activities could also result in the uncovering and transfer of unexploded and discarded munitions. Historical munitions disposals sites are marked on nautical charts and the U.S. Army Corps of Engineers requires historical record searching of sites to prevent this issue (Michel et al., 2013).

Dredging activities also directly conflict with prehistorical sites and shipwrecks. The dredge equipment and ground tackle for moorings can directly damage these sites. In the U.S., shipwreck remains have been damaged by dredging activities, and prehistorical artifacts have been pumped ashore as a result of renourishment. Indirect impacts include the uncovering or burial of historical resources. BOEM is required by the National Historic Preservation Act to protect historical resources. GIS and sonar technology is used to survey potential borrow sites for historical resources. Buffers around U.S. historic sites where no dredging or anchoring can occur have ranged from 98 feet (30 meters) to about 1811 feet (360 meters) (Michel et al., 2004).

Based on the nature of sand and gravel mining activities and conflicts listed in the literature above, we can assume that dredging activities will also conflict with uses such as shipping, offshore aquaculture, marine cables, and other marine infrastructure.

Permitting sand and gravel mining

[This section still to be completed.]

Potential along Washington's Pacific coast/Future trends and factors

[This section still to be completed.]

Gas hydrate mining

Gas hydrates are a mixture of gas and water which, under low temperature and high pressures, forms a solid ice-like structure. The main type of gas in hydrates is methane (Bureau of Ocean Energy Management, 2012a). In marine systems, methane gas is produced by organic decomposition deep within the sediment. As the methane migrates up through the sediment column, it begins to cool (P. Johnson, personal communication, December 3, 2014). Under these cooler conditions and high pressures within the sediment, the methane combines with water to form a solid ice-like structure which is called a hydrate (Bureau of Ocean Energy Management, 2012a).

The depth, temperature, and pressure range at which the hydrates form is termed the hydrate stability zone (Consortium for Ocean Leadership, 2013). On the Washington margin, the hydrate stability zone begins at about 500 meters (1650 feet) water depth. The hydrates can occur on the surface of the seafloor and can be distributed within the sediment column down to 200 meters (656 feet) (P. Johnson, personal communication, December 3, 2014.) At depths too shallow or too warm, the hydrate stability zone ends, the gas hydrates will "dissociate" and the methane will dissolve into the surrounding water (Hautala, Solomon, Johnson, Harris, & Miller, 2014). Methane hydrates of a sufficient size may be brought up to the surface of the ocean, where they will continue to dissociate into gas and water. The hydrates brought to the surface can be lit with a match and the methane emitting from the hydrate will burn.

Methane is a natural gas and can be used as an energy source. Methane hydrate resources are estimated by BOEM, Department of Energy, and other sources to be the one of the largest sources of organic carbon on earth (Consortium for Ocean Leadership, 2013; Hautala et al., 2014). This has been a primary driver in the interest of using gas hydrates for energy production. In the Methane Hydrate Research and Development Act of 2000, congress projected a shortfall in natural gas supply by 2020. The Act identified the potential for methane hydrates to help alleviate the projected shortfall, and authorized federal funding for a methane hydrate research program. Since 2000, significant U.S. funding has been invested in exploring gas hydrates for natural gas resources (Boswell, 2009).

While there is currently no commercial scale production of methane from gas hydrates, ongoing research continues to advance understanding of the gas hydrate system and the potential for methane recovery. Two exploration and production studies have been recently conducted in the U.S., one on the continental slope of northern Alaska, and other in the Gulf of Mexico. Production testing in land-based locations in Alaska and Canada, and offshore testing in Japan indicate that natural gas can be produced from methane hydrates using existing oil and gas production technology (Consortium for Ocean Leadership, 2013).

Gas hydrate mining equipment and infrastructure

Based on preliminary extraction tests, it appears that oil and gas infrastructure can be easily adapted to gas hydrate extraction (Consortium for Ocean Leadership, 2013). The summary that follows briefly describes the main tools currently used to explore for methane hydrates and some the main components of offshore oil and gas equipment and supporting infrastructure to provide context to potential gas hydrate exploration and production activities.

Tool that have been used to characterize gas hydrate resources include seismic and electromagnetic surveying, shallow and deep coring, well logging, and logging while drilling (Consortium for Ocean Leadership, 2013). Seismic surveys utilize shock waves sent through the water and sediment which then refract back to a receiver either on a floating or submerged receiver. The most common technology used for offshore oil and gas exploration utilizes airguns, which transmit acoustic energy through the water column and into the subsurface. Seismic data is generally collect using multiple vessels (National Oceanic and Atmospheric Administration, 2013).

Well logging and logging while drilling utilizes drilling and coring methods to take samples of the material within the well. Exploratory wells for offshore oil and gas are often drilled utilizing a mobile offshore drilling unit. These units can be fixed, semisubmersible, or a floating drill ship (Bureau of Ocean Energy Management, 2012b). Floating vessels are held over a well by either a mooring system or through a dynamic positioning system. Fixed platform structures are grounded on the seafloor, utilizing lower support legs to stabilize the rig. Each of these structures often requires the use of several support vessels and support aircraft (Bureau of Ocean Energy Management, 2012b; National Oceanic and Atmospheric Administration, 2013).

Production and storage facilities are similar to exploration platforms. They come in multiple designs capable of various water depths. Fixed structures, semi-submersible, and floating facilities are used throughout the world. Floating platforms are moored with line systems and anchors, while fixed structures have support legs attached to the seafloor. Facilities have been moored at over 7,000 feet (Office of Ocean Exploration and Research, 2010). Offshore processing facilities may also occur on or floating next to the platforms. Underwater pipelines and coastal support infrastructure, such as pipeline landfalls, processing facilities, and pipe yards) (Bureau of Ocean Energy Management, 2012b) may also accompany exploration and commercial production of methane hydrates.

Potential use compatibilities

[This section still to be completed.]

Environmental impacts

Environment impacts specific to gas hydrate mining are unknown. However, since the infrastructure and production technology for gas hydrate extraction is anticipated to be similar to oil and gas (Consortium for Ocean Leadership, 2013), environmental effects from offshore oil and gas production can be extrapolated to gas hydrate mining. Offshore drilling consists of multiple stages of activities. These include exploration, development, operation, and decommissioning. Each of these activity phases will have different impacts depending upon the specific activity. Some activities may be temporary, while others may occur throughout each phase, although at varying intensities (Bureau of Ocean Energy Management, 2012b).

The following is a brief summary of the general environmental concerns and impacts related to the physical presence and activities of offshore oil and gas production. This summary is primarily compiled from information available in the Programmatic Environmental Impact Statement (PEIS) produced by BOEM for the 2012-2017 offshore oil and gas lease block plans for Outer Continental Shelf (OCS) sites in the Gulf of Mexico and Alaska (Bureau of Ocean Energy Management, 2012b). Information from other sources is included when available. The specific effects to water quality, habitat, and species within Washington OCS waters from any proposed gas hydrate mining will depend upon the specific activities and intensities, and will be directly assessed in an EIS for any proposed lease block plans and individual leases.

Water quality

Activities that can affect water quality include disturbance of bottom sediments, wastes and disposals, vessel traffic, well drilling, and operational discharges. During offshore oil and gas drilling, drilling muds are used for lubrication and cooling of the drill bit and pipe. Some water-based and synthetic based muds are permitted for ocean discharge, while others are required to be disposed of onshore. Offshore disposal of muds and drill cuttings can have localized environmental impacts and are regulated by NPDES permits (Bureau of Ocean Energy Management, 2012b). While drill cuttings and muds can cause some impacts to benthic species in the immediate vicinity of the discharges, it is unclear whether this has a significant impact at the community-level scale (California Coastal Commission, 2013).

The largest discharge from oil and gas extraction is from produced water (water that is brought to the surface from an oil-bearing formation). Produced waters can have elevated concentrations of hydrocarbons, metals, and salts. Hydrocarbons in produced water discharges are a major environmental concern. Produced water is generally treated and must meet NPDES standards before discharge. Water and sediment quality may be degraded in the immediate area of discharge (Bureau of Ocean Energy Management, 2012b). In California, studies have indicated that sublethal effects to invertebrates could occur from produced water concentrations expected up to 100 meters from discharge locations. It is unclear, however, if these sublethal effects translate to population effects (California Coastal Commission, 2013).

The construction and placement of drilling units, wells, platforms, anchoring, and mooring may result in bottom disturbance and temporary increases in turbidity. Pipeline trenching may also result in bottom disturbance and increased turbidity. This is an unavoidable impact, but is expected to be temporary (Bureau of Ocean Energy Management, 2012b).

Accidental spills and other discharge events can occur. With regards to methane, it is possible that decreased oxygen levels could occur during a discharge event due to microbial activity. However, evidence from the Deepwater Horizon spill event indicates that natural gas released from a well is rapidly broken down by bacterial activity (Bureau of Ocean Energy Management, 2012b).

Air quality

Emissions from oil and gas drilling operations may affect air quality. Emissions are produced from a variety of activities. Air quality effects from offshore oil and gas operations and accidental spills within the Gulf of Mexico are expected to be minor to moderate with temporary effects. Catastrophic discharge events may result in air emissions lasting for days or months, although levels would eventually return to pre-event levels after the well is capped. Adverse effects on humans and wildlife may have long-term consequences from the exposure (Bureau of Ocean Energy Management, 2012b). Air quality effects from methane hydrate mining can be difficult to compare, since some of the emissions may be different from conventional oil and gas; other emissions, such as from supporting vessels, engines, cargo transport vessels, etc, may be similar.

Noise

Several routine operations for offshore oil and gas produce noise. These activities include exploration, construction activities such as pile driving and trenching, operational noise from platforms, ships, and aircraft, and demolition activities. A study from BOEM determined that seismic surveys may have a potentially adverse effect on marine mammals, sea turtles, fishes, and commercial and recreational fisheries while other survey activities were found to have negligible or no measurable noise impacts. Construction noises may disturb fishes, sea turtles, marine mammals, and birds in the near vicinity of the operation. Gas eruption from loss of well control may also be significant enough to harass or injure marine mammals, depending upon their proximity to the well. Marine mammals, sea turtles and fish could be affected by the noise and shock waves from explosives during demolition. Specific effects from noise depend upon the species hearing capabilities and the type, frequency, and intensity of noise generated (Bureau of Ocean Energy Management, 2012b).

Habitats

Benthic habitat can be disturbed through well drilling, anchors, bottom-fixed platform structures, pipeline trenching, and seabed equipment. Movement of anchors and mooring lines from floating platforms and support vessels may have a more chronic impact on the seafloor. In the Gulf of Mexico, anchor scars were detected up to two miles from a well location. Sediment contamination from discharges and temporary increases in turbidity may also impact seafloor habitat. Essential fish habitat could be affected by these same activities (Bureau of Ocean Energy Management, 2012b).

Pelagic habitat can be affected by platform and pipeline placement, drilling activity, seismic surveys, platform lighting, aircraft and vessel traffic, and discharges. Discharges can affect water quality, although this impact is has been estimated to be minimal in the Gulf of Mexico and Alaska. Offshore platforms can act as artificial reefs, and can be colonized by sessile organisms and attract mobile organisms, which is a shift in the normal habitat of the open ocean. Overall, in the Gulf of Mexico and Alaska pelagic habitat impacts are excepted to be negligible to minor (Bureau of Ocean Energy Management, 2012b).

Coastal and estuarine habitats could be impacted by the construction of coastal support infrastructure, increased vessel traffic to offshore platforms, and possible installation of pipelines. The specific degree and what habitat types affected will depend upon the specific activity, location, and support infrastructure needs. Federal, state, and local permits will be required and are expected to minimize impacts through mitigation and appropriate siting (Bureau of Ocean Energy Management, 2012b).

Mammals

Specific potential effects to marine mammals will depend upon the species and level of activities. Some general potential effects listed in the 2012-2017 Programmatic Environmental Impact Statement (Bureau of Ocean Energy Management, 2012b) include: collisions with support vessels, injury and disruption of normal behavior from seismic exploration, behavior disruption from construction, operation, and support vessels, physical disturbance or reduced habitat quality from onshore and offshore construction, toxicity from produced water and drilling muds, ingestion or entanglement from solid wastes and debris, toxicity from spills. Predicted impacts to marine mammals in the Gulf of Mexico and Alaska lease block areas are expected to range from negligible to moderate (Bureau of Ocean Energy Management, 2012b). Impacts to marine mammals specific to the Washington coast from any offshore drilling activities will be assessed during an environmental impact statement as a part of the permitting process.

Birds

Activities from offshore oil and gas that may negatively impact birds include offshore structure placement and pipeline trenching, offshore structure removal, operational discharges and wastes, vessel and aircraft traffic, onshore construction, and noise. These activities may impact birds by either affecting their habitat, life stages, or behaviors. Collisions with vessels, platforms, and aircraft, exposure to discharges, ingestion of trash or debris, loss or degradation of habitat, and behavioral disturbance are potential impacts listed within the Programmatic EIS for 2012-2017 BOEM leasing program (Bureau of Ocean Energy Management, 2012b). Collisions with platforms in the northern Gulf of Mexico are estimated to be at least 50 birds per platform a year; this is likely an underestimate. While these activities may impact individual birds, population effects from routine operations in the Gulf of Mexico are not likely. Platforms in the Gulf of Mexico have been observed to be used by overwintering birds as a rest point. Impacts to birds in the Gulf of Mexico and Alaska are estimated to be negligible to moderate (Bureau of Ocean Energy Management, 2012b).

Fish

Offshore oil and gas routine operational activities that have the potential to impact fish species include platform lighting, increased ship traffic, vessel discharge and miscellaneous discharges. BOEM indicates that these impacts are expected to be minimal to fish populations. Exploration and site development activities that could impact fish include noise from seismic surveys, drilling, platform placement, and pipeline activities. Discharges of drilling muds and cuttings could impact fish by contaminating food resources. Although these activities can directly impact bottom fish, it is expected to be localized the immediate vicinity of the activity and BOEM has estimated no population-level impacts to fish communities in the northern Gulf of Mexico and Alaska as a result of their 2012-2017 block leasing plan (Bureau of Ocean Energy Management, 2012b).

Benthic invertebrates that prefer hard habitat could colonize the platforms and exposed pipelines. Fish can also be attracted to oil and gas platforms to feed on colonizing organisms and other attracted fish. This represents a change of community structure and behavior of fishes. The positive and negative effects of these fish aggregations will depend upon the life history of the fish and fisheries management in other areas (Bureau of Ocean Energy Management, 2012b).

Environmental impact statements for any proposed offshore methane mining activity in Washington waters will address fish species specific to our region, including listed endangered and threatened species.

Sea turtles

Sea turtles may potentially be impacted by offshore oil and gas noise, collisions with vessels, and toxicity from discharges. Noise from seismic surveys, construction of platforms and pipelines, and platform demolition by explosives can kill, injury, or disrupt behavior of turtles near the activity (Bureau of Ocean Energy Management, 2012b). Disturbance effects to sea turtles from any proposed offshore methane mining in Washington will be evaluated in an environmental impact statement.

Invertebrates

Activities that can impact invertebrates include vessel and other discharges, offshore lighting, noise for seismic surveys and bottom disturbance activities, and release of drilling muds and cuttings. Invertebrates can be killed, injured or displaced from drilling, platform construction, pipeline trenching, and disturbance from anchors. Disturbed sediments may also resettle and bury or damage the gills of some benthic invertebrates. Recolonization of these areas by invertebrates may be relatively rapid, but the return of community composition to pre-disturbance levels may take longer (Bureau of Ocean Energy Management, 2012b).

Drilling muds may contain chemicals toxic to marine invertebrates, but these effects may be species dependent. This may chance the benthic community composition around the well. Toxic effects from produced water discharges are not anticipated because of the NPDES permit requirements for discharge of this material. (Bureau of Ocean Energy Management, 2012b).

As mentioned earlier, invertebrates which prefer hard-bottom substrates may colonize the platform and pipeline structures. These structures may become habitat for native and introduced species (Bureau of Ocean Energy Management, 2012b).

Safety hazards (instability from drilling)

Destabilization of the site could cause safety issues, a potential release of methane into the sediments and water column and destabilization of the substrate. Industry is working to figure these out, as it is safety hazard to their operations. Limited information was uncovered about what the environmental effects would be. Different than oil and other gases, literature did not have much to say about what the potential environmental effects of a catastrophic event for a methane mining activity. About half of the methane releases from Deepwater Horizon spill were estimated to be consumed by bacteria (University of Georgia, 2014).

Methane releases and climate change

Methane hydrates form within a stability zone dependent upon temperature and pressure. When pressure decreases or temperature increases, the hydrates can dissociate and release methane into the water column. Global climate change is influencing the temperature within some of the world's oceans, and could lead to increased release of methane gas into the water column and possibly into the atmosphere. Studies performed on the Washington coastal margin suggest a substantial volume of methane gas has the potential to be released from hydrates due to contemporary climate change (Hautala et al., 2014).

Methane seeps are a natural occurrence along the Washington coastal margin, and are currently a focus of study (Hautala et al., 2014; Johnson, Solomon, Harris, Salmi, & Berg, 2014; Salmi, Johnson, Leifer, & Keister, 2011). The estimated amount of methane emitted from these seeps is 0.1 metric tons per year, which is approximately equivalent to the amount of gas emitted from the 2010 Deepwater Horizon spill. Predicted changes to bottom water temperatures from climate change could shift the hydrate stability zone, and could increase methane emission by a factor of four by 2100 (Hautala et al., 2014).

Methane is a hydrocarbon and a greenhouse gas. Methane dissolved into the water column could influence ocean acidification (Hautala et al., 2014), while methane released into air could contribute to further global climate change (Consortium for Ocean Leadership, 2013; Ruppel & Noserale, 2012). While these factors are important to understand, the natural methane seeps and potential zone for increased methane dissociation from climate change are not the methane sources currently targeted for energy mining. Methane hydrates currently targeted for mining are located deeper within the hydrate stability zone.

Potential use conflicts

Methane hydrate mining is currently not a commercial use in any part of the world, yet there are several potential use conflicts that could arise if the industry were to be proposed off of the Washington coastal margin. The infrastructure and production technology for gas hydrate extraction is anticipated to be similar to offshore oil and gas (Consortium for Ocean Leadership, 2013). To help inform the potential use conflicts that may arise from gas hydrate mining, known and potential use conflicts from the BOEM 2012-2017 PEIS for offshore oil and gas lease block plans in the Gulf of Mexico and Alaska (Bureau of Ocean Energy Management, 2012b) are summarized below. Specific use conflicts along the Washington coast will depend upon the nature intensity of this potential new activity.

Commercial and recreational fisheries

Commercial fishermen may be affected by offshore oil and gas operations by causing changes in the distribution or abundance of fishery resources, reducing the catchability of fish, precluding fishers from accessing viable fishing areas, or causing losses of or damage to equipment or vessels. Impact will depend upon the fishery, fishing method or year, and nature of particular structure. Navigation and access to the fishing grounds may be disturbed. A safety zone for vessels longer than 100 feet may be established up to 1,640 feet around each production platform, which would encompass up to approximately 198 acres of surface area per platform. Decommissioning: all wellheads, casings, pilings, and other obstructions will be removed to a depth of at least 15 feet below the mud line or other approved depth. This would decrease a small area allowable for trawl fishing. Longlining not affected after decommissioning. An offshore environmental cost model assumes 0.5 mile buffer around gas and oil structures decreasing the area available for fishing. (pg 1206)

Recreational fisherman: specific effects mainly tied to any effects on the targeted species. The platforms may have a positive effect on the availability of recreational fishing opportunities (pg 1206) In the GOM up to 51% of party boat fishing trips were within 300 feet of an oil or gas structure because the structures are known to aggregate pelagic fish.

It is difficult to extrapolate the effect of a spill or catastrophic event from an oil and gas platform to methane hydrate mining, but it is possible that commercial and recreational fisheries would be impacted by consumer perception of food safety and therefore reduce spending. Any closure of fishing grounds would have impact on commercial and recreational fishermen.

In Alaska, there has been a history of conflicts between commercial fisheries and seismic exploration vessels. Loss of gear, including crab pots and longlines. Some studies have found a temporary reduction in fisheries catch during or following seismic surveys. (pg 1210)

Construction of pipelines can result in entanglement hazards for some types of fishing gear (bottom trawl, crab pots). Recreational fisheries can experience disruptions to access fishing grounds, lost gear, and reductions of catch following seismic surveys.

Commercial and recreational fishing could be affected if behavioral changes in target species (MMS 2007d) occur as a result of exposure to seismic surveys (see Section 4.4.11). The effect is expected to be temporary. (Bureau of Ocean Energy Management, 2012b)

Tourism and recreation

[This section to be completed.]

Archaeological and cultural resources

[This section to be completed.]

Permitting gas hydrate mining

[This section to be completed.]

Future trends and factors in WA/Potential along Washington's Pacific coast

High gas hydrate concentrations in sand are currently the primary targets for exploration. Conventional oil and gas technology favors methane extraction from sand dominated gas hydrate reservoirs. In addition, gas hydrates can occur in various percentages within marine sediments. The Gulf of Mexico, for example, has estimated gas hydrate saturation at 50-90% (Consortium for Ocean Leadership, 2013). By comparison, the Washington coastal margin has an estimated 5% gas hydrate saturation (Hautala et al., 2014). Based on resource assessments and the status of methane hydrate research, the U.S. Department of Energy and the Consortium for Ocean Leadership identified the Gulf of Mexico and the New Jersey coastal margin as top priorities for scientific methane hydrate drilling (Consortium for Ocean Leadership, 2013).

Production of methane from gas hydrates is currently in the development stage; no commercial operations exist. Field scale tests for methane production from gas hydrates have been limited to short durations (less than one month). A six-day offshore field test in Japan established that methane gas production is feasible. However, the methane produced was one to two magnitudes lower than a typical commercial rate for gas accumulation. Initial production rates are expected to be low because it may take years before a well reaches its maximum production rate. Longer tests are needed before commercial viability of this resource can be established (Consortium for Ocean Leadership, 2013).

The United States federal government continues to provide significant investments and coordinated research plans for assessing gas hydrates and developing production technologies (Consortium for Ocean Leadership, 2013; National Energy Technology Laboratory, 2012). It is possible that commercial scale production of methane from gas hydrates in Alaska and offshore Japan could begin within the next 10 to 20 years (Boswell, 2009; Consortium for Ocean Leadership, 2013). Since conventional oil and gas equipment can be used to mine methane from gas hydrates, the roadblocks to commercial scale production relate more to the economics of hydrate extraction (Consortium for Ocean Leadership, 2013).

Gas hydrate resources within the Washington coastal margin have been estimated by BOEM. These are modeled estimates of in-place gas hydrates and do not assess technically recoverable resources (Bureau of Ocean Energy Management, 2012a). Researchers at the University of Washington are currently mapping a more detailed resource assessment of gas hydrates in the Washing margin (P. Johnson, personal communication, December 3, 2014). Although gas hydrate volumes within the Washington margin are estimated to be quite substantial, the average gas hydrate saturation is assumed to be 5% (Hautala et al., 2014). Therefore, methane hydrate mining within Plan is likely not a primary target compared to methane rich highly concentrated sands in the Gulf of Mexico and Atlantic margin.

Other mining activities

Preliminary research was conducted to understand the potential for uranium extraction and deep seabed mineral resource mining activities with the MSP Study Area. Uranium extraction is the extraction of uranium from seawater for energy purposes. Deep seabed mineral resource mining is the mining of polymetallic nodules, ferromanganese crusts, and massive sulphides from the seafloor. Literature and other resources indicated that uranium extraction and deep seabed mineral mining activities are generally early in development and are not targeting Washington waters ("International Seabed Authority," 2014; G. Gill, personal communication, November 20th, 2014). Therefore, we assessed that both of these potential activities are highly unlikely to occur in the MSP Study Area in the near future and are therefore are not described further within the MSP.

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2.11 Climate Change

Introduction

Climate change is a global phenomenon that will impact the MSP Study Area in a variety of ways. While the future effects can be projected based on the best available science, the precise magnitude, duration, and frequency of the effects are not certain. In the MSP Study Area, the current uses and potential uses, coastal populations, habitats, and wildlife are likely to experience changes. This section provides information on the potential impacts of global climate change on the MSP Study Area. Scientific research into the effects of climate change continues to provide improved information on what can be expected, but the real-life impacts will depend on how significant the changes in conditions are, the degree of vulnerability of resources and their responses to those changes, as well as any cumulative impacts.

Climate change modeling provides projections based on varied scenarios that lead to a range of results. These ranges of projected impacts can be used for planning purposes. This section provides a review of potential impacts of climate change, with projections from climate change models, however they may shift as our understanding of the issue becomes more refined. More detailed information and in-depth analysis can be found in many scientific reports. Climate change has the potential to greatly alter the physical, ecological, economic, and social environment of the MSP Study Area and should be considered with any potential new uses of the area.

Summary of climate change

Climate change can be defined as any substantial change in a measure of climate, such as temperature or precipitation, which lasts for decades or longer. During previous periods of time this change has been due to natural factors, but the changes observed now are primarily caused by human activities (U.S. Environmental Protection Agency, 2016). Shifting climate has the potential to drive significant changes in the air, land, and sea that will in turn influence the lives of the human and ecological communities that rely on them. This section includes an explanation of the forces driving global climate changes, as well as the range of impacts that are projected to result in the MSP Study Area.

Greenhouse gases

The primary driver of human-caused climate change is through the addition of significant amounts of greenhouse gases into the atmosphere, such as the burning of fossil fuels for electricity generation and transportation (U.S. Environmental Protection Agency, 2016). The major greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases[1] (U.S. Environmental Protection Agency, 2016). They are called greenhouse gases because they trap heat in the lower part of the atmosphere and as the volume of gases increases, so does the amount of heat trapped. With this extra heat trapped in the atmosphere, it leads to higher air temperatures near the surface of the Earth, higher water temperatures in the oceans, and altered weather patterns. Humans have added significant quantities of greenhouse gases to the atmosphere by burning fossil fuels and clearing forests (U.S. Environmental Protection Agency, 2016).

[1] Fluorinated gases are gases that contain fluorine including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (U.S. Environmental Protection Agency, 2016).

Many of the major greenhouse gases can remain in the atmosphere for tens to thousands of years after being released, while some substances have shorter atmospheric lifetimes but still affect the climate. Carbon dioxide is not destroyed over time, but rather moves between the atmosphere, ocean, and land. Therefore, some CO_2 may remain in the atmosphere for thousands of years while some is absorbed quickly into the ocean. The greenhouse gases all mix together in the lower part of the atmosphere and are distributed globally so that the concentrations of the gases are similar across the planet. The resulting climate change impacts from these greenhouse gases are also global. One exception to this is in areas that are large sources or sinks of a specific gas where the concentration varies from the global concentration (U.S. Environmental Protection Agency, 2016).

Climate change impacts

The increase in greenhouse gas emissions and resulting climate change have already impacted atmospheric conditions and are projected to continue to do so. Some of the impacts are discussed below including changes in air temperature, precipitation, and air circulation patterns.

Air temperature

The Pacific Northwest (PNW) has experienced warming of 1.3^{o}F between 1895 and 2011. During the same time period, the frost-free season also lengthened by 35 days (±6 days) (Snover, Mauger, Whitely Binder, Krosby, & Tohver, 2013). Scientists project the temperature in the PNW to rise by 5.8^{o}F by the 2050s for a high greenhouse gas emissions scenario when compared to the average temperature from 1950-1999. Extreme heat events are projected to become more frequent while extreme cold events become less frequent (Snover et al., 2013).

Precipitation

There has been no long-term trend of wetter or drier conditions in Pacific Northwest precipitation from 1895-2011 (Snover et al., 2013). In the PNW, annual precipitation is projected to have relatively small changes, with models projecting a change of -4% to +14% during the 2050s as compared to the average for 1950-1999 (Snover et al., 2013). The projections for seasonal changes are also mixed with most models projecting drier summers and a majority of models projecting increases in precipitation for the rest of the year. Scientists project an increase in the number of heavy rainfall events and less snow accumulation (Snover et al., 2013).

El Niño-Southern Oscillation and Pacific Decadal Oscillation

Two important climate patterns that impact climate variability along the Pacific Coast of Washington are the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Although ENSO and PDO are unique from the climate change discussed in this chapter, they affect similar components of the climate system. Both ENSO and PDO alter regional surface winds, air temperatures, and precipitation and are distinguished by warm and cold phases. In the northeast Pacific, the observable responses to a warm phase of ENSO include warm upper ocean temperatures, winds that are favorable to downwelling, reduced primary productivity, the appearance of southern marine species not normally part of this range, and elevated average water level. During a cold phase, sometimes referred to as La Niña, the opposite will occur (Miller, Shishido, Antrim, & Bowlby, 2013; Moore, Mantua, Hickey, & Trainer, 2010).

The PDO and ENSO occur on different time scales, but positive phases of ENSO tend to be associated with positive phases of the PDO. In the northeast Pacific, PDO positive phases cause warm temperatures, positive sea level pressure, and higher sea level (Miller et al., 2013). A typical ENSO event will last for 6-18 months and a typical PDO event will last for 20-30 years (Moore et al., 2010). It can be challenging to distinguish between the long-term climate change trends and climate cycles like these that occur on annual to decadal time scales. It is still unclear what impact climate change will have on ENSO and PDO, or whether it will force changes in either frequency or intensity (Miller et al., 2013; Vecchi & Wittenberg, 2010).

Ocean and coastal impacts

Climate change, due to human-caused increases in greenhouse gases, influences many components of marine ecosystems. Increased CO_2 in the atmosphere directly causes increasing ocean temperatures and increasing acidity. The increase in ocean temperatures drives additional changes including rising sea level, increased ocean stratification, decreased sea-ice extent, and altered patterns of ocean circulation, precipitation, and freshwater input (Doney et al., 2012). Ocean warming and changes in circulation also lead to reduced subsurface oxygen (O_2) concentrations (Doney et al., 2012). Projected changes in ocean temperature, dissolved oxygen, sea level rise, flooding, erosion, storms, ocean acidification, and harmful algal blooms are briefly discussed in this section.

Ocean temperature

Ocean temperature can be broken down into both the sea surface temperature and ocean heat content. Water has a higher heat capacity than air, therefore the ocean can absorb large amounts of heat with only a slight increase in temperature. The oceans have not warmed as much as the atmosphere, even though the oceans have absorbed a majority of the Earth's extra heat (U.S. Environmental Protection Agency, 2016). The ocean has absorbed approximately 80% of the heat in the climate system associated with greenhouse gas emissions during the last fifty years (P. W. Mote, Petersen, Reeder, Shipman, & Whitely Binder, 2008). The upper layer of the ocean is generally expected to absorb heat most rapidly and warm the fastest due to its proximity to the atmosphere. It will take longer, likely centuries, for the deep ocean to warm as global circulation patterns mix the warmer surface water with the deeper colder water (Miller et al., 2013).

Sea surface temperature has increased at an average rate of 0.13°F per decade between 1901 and 2015 (U.S. Environmental Protection Agency, 2016). Mote and Salathe (2010), projected increases in sea surface temperature of about 2.2°F to the 2030-2059 future annual cycle from the 1970-1999 average.

A warming ocean has consequences for sea level because water expands slightly as it gets warmer. The heat in ocean surface waters also provides energy for storms, influences weather patterns, and can change ocean currents (U.S. Environmental Protection Agency, 2016). Increases in sea surface temperature and the resulting changes in ocean circulation patterns can affect which species are present in marine ecosystems, alter migration and breeding patterns, threaten corals, and change the frequency and intensity of harmful algal blooms (U.S. Environmental Protection Agency, 2016). Increasing sea surface temperatures could weaken the circulation patterns responsible for the upwelling of water and nutrients from the deep sea to surface waters, which could contribute to declines in fish populations and the human impacts related to decreased food supply and job impacts in the fishing industry (U.S. Environmental Protection Agency, 2016).

Hypoxia and anoxia

As climate changes, it is expected to impact the concentration of dissolved oxygen in the ocean. Hypoxia is the state of low dissolved oxygen concentrations that causes stress to aquatic animals and anoxia is the state of no dissolved oxygen in water. Hypoxia is associated with large scale ocean circulation and productivity as well as local upwelling. In the MSP Study Area, upwelling of water that is low in dissolved oxygen and high in nutrients promotes increased primary productivity. Large phytoplankton blooms in turn support the food web leading to increased waste products. As waste products sink through the water they are broken down by bacteria that respire and use dissolved oxygen in the process, further decreasing the available dissolved oxygen (Miller et al., 2013).

The coast of Washington regularly experiences a seasonal cycle of dissolved oxygen concentrations. In the winter, waters at depth have relatively high dissolved oxygen concentrations due to decreased biological productivity and frequent storms producing winds that are favorable to downwelling. In the summer, waters at depth have decreasing dissolved oxygen levels that often reach hypoxic levels. This is due to prevailing winds that are favorable to upwelling as well as high biological productivity. Increases in the severity and frequency of hypoxia are projected to reduce species diversity, decrease organism size, and decrease the efficiency of energy transfer between trophic levels (Miller et al., 2013).

Global climate models project that dissolved oxygen concentrations in the ocean will decline. As ocean temperatures increase, the solubility of oxygen will decrease. The stratification of the ocean will increase as a result of the surface water experiencing increasing temperature and decreasing salinity (due to increasing freshwater input). The combination of these factors will reduce dissolved oxygen concentrations as the denser water is not able to mix with surface waters and experiences longer periods of respiration at depth (Miller et al., 2013).

Sea level rise and flooding

The temperature of the Earth and sea level are connected in multiple ways. As discussed above, when water warms it expands slightly. This becomes significant when measured over the entire depth of the oceans. Additionally, the volume of the water in the oceans can change based on changes in the volume of water and ice on land. As glaciers and ice sheets melt due to increasing temperatures, this will increase the volume of water in the oceans. Sea level rise is a threat to coastal communities through shoreline erosion, contributions to coastal flooding, and inundation of low-lying land. Higher sea level can also threaten coastal infrastructure as higher storm surges increase the likelihood of flooding (U.S. Environmental Protection Agency, 2016).

Since 1993, average sea level has risen at a rate of 0.11 to 0.14 inches per year (U.S. Environmental Protection Agency, 2016). Global sea level rise is projected to increase by 11 to 38 inches by 2100 as compared to 1985 to 2005 levels (Snover et al., 2013).

Although global sea levels are rising and predicted to continue to do so, there are local and regional factors that influence the amount of sea level rise that is predicted for the MSP Study Area. This variability in sea level rise is greatly influenced by the fact that the Northwest is a geologically active area with an active subduction zone. The subduction of the Juan de Fuca plate beneath the North America plate forces vertical land motion that can either increase or decrease the overall rate of regional sea level rise (Dalton, Mote, & Snover, 2013; Miller et al., 2013). On the Olympic Peninsula, the coast has experienced vertical uplift at the same rate as sea level rise and there is the potential for a net decrease in local observed sea level.[2] In other locations, subsidence of land may contribute to higher sea level rise (Dalton et al., 2013).

[2] For the NW Olympic Peninsula coast, projected sea level rise ranges from -5” to 14” by 2050 and -9” to 35” by 2100. For the central and southern coast, projected sea level rise ranges from 1” to 18” by 2050 and 2” to 43” by 2100 (P. W. Mote, Petersen, Reeder, Shipman, & Whitely Binder, 2008)

Changing wind stress patterns may also impact sea level rise along the coast.[3] Since approximately 1980, the North Pacific has been under PDO warm phase conditions. The associated predominant wind stress patterns have regionally moderated sea level rise trends that were otherwise seen globally. If there is a shift to PDO cold phase conditions, there may be higher rates of sea level rise along the West Coast (Dalton et al., 2013).

A number of coastal impacts can result from sea level rise and affect the MSP Study Area. Some low-lying areas will become permanently inundated depending on the shoreline characteristics and the rate of sea level rise. Coastal rivers may also see increased flooding, both in the extent and depth of flood waters, as it will be harder for rivers to drain into the ocean. High river flows are also expected to increase in size and frequency as a result of climate change. Similarly, high tide and storm surge events will be amplified as sea level increases. This in turn will expose more areas to erosion and potentially threaten coastal infrastructure (Snover et al., 2013).

Storms and erosion

Scientists project storms to increase in both intensity and frequency on a global scale as a result of climate change. Storms can directly impact the coast of the MSP Study Area, but even storms that are further offshore can still impact the area by increasing wave heights and causing changes in wave direction. These can cause erosion or redistribute sediment which alters shallow marine and intertidal habitats (Miller et al., 2013). Global climate models project that storm tracks in the PNW will be driving northward over time and there will be an increase in the intensity of the precipitation associated with the storms. Other associated impacts are likely to include increasing wave heights and the potential for large storm surges which could increase coastal erosion (Miller et al., 2013).

Overall, the erosion along the beaches in southwest Washington is influenced by reduced sediment supply, gradual sea level rise, and a northward shift in Pacific winter storm tracks. The sandy ocean beaches and dunes are shaped by a high-energy system with waves that shift seasonally in both energy and direction. Beach erosion occurs when large waves meet the beach at a steeper angle from the south. This is enhanced during El Niño conditions when the sea level is higher in the winter. As climate change continues to shift conditions, it is likely that these erosion events will continue or increase due to increasing sea level rise and winter storms. The Washington Coast has several areas of high erosion, including Washaway Beach which has the fastest erosion on the Pacific coast. On average, Washaway Beach has been losing 65 ft. of beach annually since the 1880s. (Climate Impacts Group, 2009).

Ocean acidification

Ocean acidification is a reduction in the pH of the ocean for an extended period of time that is primarily caused by the uptake of carbon dioxide (CO_2) from the atmosphere. The ocean absorbs approximately one-third of atmospheric CO_2 generated through human activities (Chan et al., 2016; Marshall et al., 2017). Additional sources driving acidification in Washington include local input of nutrients, nitrogen oxides and sulfur oxide gases, upwelling, and hypoxia. Since the mid-1700s, open ocean surface waters have become approximately 30% more acidic (Chan et al., 2016; Feely, Klinger, Newton, & Chadsey, 2012). Washington's coastal waters are projected to increase in acidity by 38% to 109% by 2100 when compared to levels from 1986-2005 (Snover et al., 2013). This correlates to an increase of roughly 150% to 200% when compared to pre-industrial levels (Snover et al., 2013).

As ocean water becomes more acidic, the concentration of carbonate ion (CO_3^{2-}) decreases. Carbonate ion is required by many marine animals and some plants to build shells, skeletons, and other

[3] Changes in atmospheric circulation can result in changes to wind stress.

hard parts by forming calcium carbonate. Calcium carbonate, usually in the form of calcite or aragonite, is also susceptible to acidification as the water becomes more chemically corrosive. Aragonite is about twice as susceptible to dissolution as calcite (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Pteropods, corals, and most larval bivalves use aragonite to build their shells, making them vulnerable to negative impacts from ocean acidification. In the northeast Pacific Ocean, aragonite-corrosive conditions are expanding much more rapidly than calcite-corrosive conditions (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Scientists predict ocean acidification will have a significant impact on shellfish populations. By 2100, ocean acidification is projected to reduce the rate at which mollusks form shells by 40% globally. It is also projected to cause a 17% decline in growth and a 34% decline in survival (Snover et al., 2013).

Organisms that are not impacted by reduced calcification are still experiencing other negative consequences from ocean acidification. Some species experience decreased growth, reproductive issues, and increased mortality. These negative impacts are felt throughout the ecosystem as the organisms normally provide habitat, shelter, and food for other organisms (Chan et al., 2016; Washington State Blue Ribbon Panel on Ocean Acidification, 2012). One example is the food web effects that may result from impacts to pteropods, which in some locations are showing signs of shell dissolution in more than 50% of the population. Many West Coast fisheries species like herring, mackerel, and salmon rely on pteropods as an important food source and are therefore vulnerable indirectly to ocean acidification (Chan et al., 2016).

While ocean acidification due to absorption of CO_2 from the atmosphere is a global phenomenon, there are local factors that increase the occurrence of regional acidification. Upwelling, nutrient and organic carbon input from land, and absorption of other acidifying gases from the atmosphere all contribute to ocean acidification on Washington's Pacific coast (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Acidified waters are most prominent in the Northwest during the spring through late summer, due to upwelling of corrosive waters from seasonally shifting winds. The acidified waters are transported up to the continental shelf, reaching surface waters in some places, and entering the estuaries. When acidified waters enter the estuaries, they can combine with inputs of nutrients and organic matter creating conditions that are even more corrosive than the waters off the coast. This acidification of coastal waters, especially within the estuaries, is a threat to the shellfish aquaculture in the region (Dalton et al., 2013).

Harmful algal blooms

Harmful algal blooms (HABs) are blooms of algae that can produce natural toxins that cause illness or death in humans and other animals. The algae can become concentrated in the flesh of filter feeding shellfish and fish. Human and animal exposure may occur through consumption of contaminated fish and shellfish, inhalation, or skin contact with contaminated water. Two of the main HABs in Washington are paralytic shellfish poisoning (PSP) caused by dinoflagellates in the genus *Alexandrium* and amnesiac shellfish poisoning caused by domoic acid created by diatoms *Pseudo-nitzschia* (Climate Impacts Group, 2009; Washington State Department of Fish and Wildlife, 2015).

HABs on the coast are considered a natural event. However, HAB magnitude, frequency, and duration are influenced by climate change through sea surface temperature and upwelling. In general, phytoplankton growth is determined by temperature, light, and the availability of nutrients. However, all HAB species will not respond in the same way to shifts in climate change factors. Marine HAB dinoflagellates are expected to have an advantage as climate changes, because they are able to swim and therefore reach nutrients in the deeper parts of the water column that other phytoplankton cannot reach (Climate Impacts Group, 2009).

Over the last 30 years, the frequency and distribution of HABs has increased. There has also been a resulting increase in human illness due to algal sources. The rising air and sea surface temperatures that are predicted with climate change may promote earlier and longer lasting HABs. In addition to increasing temperatures, HABs may be influenced by wind-driven upwelling and nutrients supplied by land runoff. Runoff into coastal estuaries may shift due to changes in the timing of snowmelt and freshwater inputs (Climate Impacts Group, 2009).

Ecological impacts

While it is challenging to project the responses of different species to the effects of climate change, certain types of responses are expected to occur. The physical and chemical changes in the ocean that result from climate change have a strong impact on the physiology and behavior of marine organisms. These effects are both direct and indirect and can also drive population and community level changes that alter how an ecosystem is structured and functions (Doney et al., 2012). Changes in the environment due to climate change could alter the structure and relationships between predators, prey, parasites, and competitors in a community and, therefore, impact the productivity of the community (Miller et al., 2013).

Another result of changes to the physical environment may be shifts in certain phases of the life cycles of organisms. These shifts in life cycles will not only impact the organisms themselves, but may alter predator and prey relationships and lead to larger changes on the ecosystem scale. Scientists have already document shifts in timing of phytoplankton blooms, which can impact organisms up the food chain. Organisms at higher trophic levels are highly dependent on phytoplankton blooms and often rely on them during a short time period in their life cycle (Miller et al., 2013).

Species shift the areas where they live, also referred to as their range, as climate changes and local conditions change. If new conditions become too extreme, some species will be able to shift to locations with more favorable conditions. Studies have documented shifts in species ranges as a result of changes in temperature. Fish species have been documented to respond to warming ocean temperatures by moving north to cooler waters or by moving to deeper waters (Miller et al., 2013). As a result of shifting ranges, some non-native species may move into new territories as they respond to changing conditions. These non-native species have the potential to cause significant impacts through ecological impacts to the food web (Miller et al., 2013).

While the same basic climate forces will be changing everywhere in the MSP Study Area and adjacent areas, each region will respond differently. The substrate, slope, and surrounding conditions will influence the impacts of climate change. The changes in climate will be experienced in different ways on the coast north of Point Grenville with steep rocky shores, the coast south of Point Grenville with sandy beaches with shallow slopes and high energy waves, and the estuaries with shallow water and protected bays and mudflats (Climate Impacts Group, 2009; Dalton et al., 2013). Some specific ecological impacts related to the various habitats of the MSP Study Area are discussed below. [4]

Pelagic

Pelagic habitats and the organisms that occupy them are expected to experience changes due to climate change factors including acidification, reduced oxygen events, shifts in metabolism due to ocean temperature changes, and changes in patterns of storminess or waves (Miller et al., 2013). Increasing surface water temperatures may increase stratification in the water column and, therefore, decrease

[4] More information on the habitats discussed here are available in Section 2.1 Ecology of Washington's Pacific Coast.

primary productivity by reducing mixing with nutrient-rich waters. However, increases in upwelling winds could increase mixing and counteract the stratification. Shifts in primary productivity related to changes in upwelling can impact the entire food web. Some plankton, like larval oysters and pteropods, that need calcium carbonate to build their shells will experience negative impacts from ocean acidification while other plankton like euphasiids may benefit from increasing water temperatures (Miller et al., 2013).

Pelagic fishes will likely be impacted by any changes in the zooplankton communities discussed above. However, the specific impacts are unclear since pelagic fish species rely on different varieties of zooplankton. It is unknown how changes in the prey availability will impact them as some fish may benefit from the changes while others may suffer from a decrease in their food source. Most pelagic fishes do experience reductions in population due to reduced oxygen in the California Current. The cumulative impacts of potential reductions in prey and oxygen could have serious consequences for pelagic fishes (Miller et al., 2013).

Seafloor

The seafloor and deep water habitats are likely to be impacted by the changes in ocean temperature, ocean acidification, hypoxia, and surface productivity that are associated with climate change. The deep sea corals that are found in the MSP Study Area are especially impacted by changes in the water temperature and acidification as they use aragonite to form their skeletons. Any resulting loss of corals would have an impact on the many species of fish and invertebrates that rely on them for habitat (Miller et al., 2013; Skewgar & Pearson, 2011).

Deepwater fishes may suffer loss of suitable habitat and decreased populations if the hypoxic or anoxic zones expand, or if the frequency of events increases. While benthic fish populations may decrease as a result of changes in primary productivity, species ranges, zooplankton community structure, acidification, and hypoxia, other organisms may experience population increases. Ecological models of food webs predict increases in biomass of benthic and pelagic invertebrates as the biomass of benthic fish decreases (Miller et al., 2013).

Kelp forest

Kelp forests are an important biogenic habitat in the MSP Study Area and support a variety of organisms. Increasing ocean temperatures are likely to impact kelp physiology, growth, reproduction, and competitive interactions. The exact impacts depend on the timing and duration of temperature changes. Some non-native species may be able to move north into MSP Study Area waters as a result of increasing temperatures. All marine algae species may experience benefits due to ocean acidification as an increase in available CO_2 could benefit their productivity. However, it is unclear if the benefits of increasing CO_2 would exceed any of the consequences caused by increasing ocean temperature. Increasing storm intensity has the potential to impact kelp forest habitats by shifting the availability of large hard substrates needed for attachment and damaging seagrasses through wave action (Miller et al., 2013).

Rocky shores

Climate change is likely to cause stress to intertidal organisms that have limited vertical ranges due to the stress of heat and exposure above and from predators below. These organisms may be forced lower into the intertidal zone to adjust to increased air temperatures. However, their predators may be able to move higher into the intertidal due to sea level rise increasing the potential for predation. Intertidal organisms will also be threatened by increasing storms and wave energy, erosion, and increased sediment delivery from rivers. Ocean acidification also threatens many intertidal organisms that may have declining survival rates based on inability to form shells. This could lead to a shift in the intertidal community structure as other organisms, like algae, can thrive with increasing CO_2 in the water (Miller et al., 2013).

Sandy beaches

As discussed above, sandy beaches are likely to experience many physical impacts from climate change. Sandy beaches offer habitat that supports prey for foraging birds, spawning habitat for forage fish, and haul-out areas for marine mammals, but this may be lost if erosion causes beach areas to coarsen and steepen due to increasing erosion and storm intensity and frequency (Miller et al., 2013).

Large coastal estuaries

Many of the key factors that drive the functioning of estuaries are affected by climate change. Changes in the annual precipitation, sea level, winds, and seasonal runoff will all impact estuaries. Flooding, erosion, coastal inundation, and saltwater intrusion into freshwater aquifers are predicted to occur as climate changes (Skewgar & Pearson, 2011). A reduction in estuarine habitats like tidal flats, estuarine, and outer coast beaches will impact associated animals like forage fish and shorebirds (Dalton et al., 2013).

Some of the impacts on the plant and animal life dependent on estuaries include wild and farmed shellfish harmed by acidifying waters and eelgrass and kelp suffering from changes in benthic nutrient cycling (Skewgar & Pearson, 2011). Increases in the occurrence of hypoxic or anoxic conditions in the estuaries would impact the distribution, abundance, and community composition of zooplankton. As sea level rise causes inundation, estuaries will likely experience habitat changes such as migration, loss, or expansion of certain habitats, thus impacting the overall composition of habitats within estuaries. For example, loss of intertidal habitat due to sea level rise would impact Dungeness crab populations. Dungeness crab rely on estuaries as nursery areas for juveniles and foraging grounds for subadults and are also susceptible to changes from ocean acidification, and hypoxia (Miller et al., 2013).

Existing uses

The impacts of climate change on the environment and ecological resources of the MSP Study Area are likely to affect current uses like fisheries, recreation and tourism, aquaculture, transportation, and tribal uses. The section below highlights some of the possible effects, however projections are still limited due to uncertainty about the degree of climate change expected and degree of vulnerability, as well as adaptability. For more information about these current uses please see Sections 2.4-2.7.

Commercial, recreational, and tribal fisheries

Climate change and the associated changes in the oceanic conditions are potential threats to commercial, recreational, and tribal fishing in the MSP Study Area. Ocean acidification is particularly concerning for shellfish populations, such as Dungeness crab and shrimp. As the ocean chemistry changes, shellfish experience slower growth rates, thinner shells, and higher mortality rates (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Shellfish have also been found to be more vulnerable when they are young. For example, in lab experiments juvenile crab experience drastically increasing mortality under increasing ocean acidification (Welch, 2013). Fisheries that rely on crab, oysters, and other shellfish could potentially experience great consequences as a result of ocean acidification (Industrial Economics Inc., 2014a). Ocean acidification does not just impact fisheries that rely on organisms that are directly affected, but also other organisms that are indirectly affected through the food web. For example, juvenile salmon rely on pteropods as an important source of food, and pteropods experience reduced shell-building and growth rates due to ocean acidification (Industrial Economics Inc., 2014a; Washington State Blue Ribbon Panel on Ocean Acidification, 2012). A decrease in an important food source could reduce salmon populations and, in turn, impact the salmon fisheries.

Finfish fisheries are likely to experience varied seasons as ocean conditions shift, although the specific impacts are unclear at this time. As the ocean temperature rises, it will impact the distribution and availability of commercial fish species. Fish populations may shift their range as a result of changing temperatures and availability of prey species. Shifting population numbers and ranges can have a significant impact on the fisheries that rely on them (Taylor, Baker, Waters, Wegge, & Wellman, 2015).

Recreation and tourism

Recreation and tourism in the MSP Study Area also has the potential to be impacted by some aspects of climate change. Increasing storms and erosion are concerns for coastal locations, particularly along the southern coast. Increased erosion can damage or destroy recreational facilities and areas. State parks and other recreational beaches and facilities in southwest Washington are already experiencing erosion and loss of facilities (Industrial Economics Inc., 2014b).

Another potential issue for the recreation and tourism industry could result from an increase in HABs due to climate change. The recreational shellfish fishery has great economic benefits for coastal communities and the state (Taylor et al., 2015). Occurrences of HABs are projected to shift in frequency, intensity, and duration as a result of rising temperatures and changes in upwelling (Climate Impacts Group, 2009). An increase in HABs could lead to more closures of recreational shellfish harvesting to protect human health and result in negative economic consequences (Dyson & Huppert, 2010).

Aquaculture

Shellfish aquaculture is vulnerable to the effects of climate change in a variety of ways. Increased sea surface temperature has the potential to negatively impact shellfish growth, reproduction, distribution, and health (Climate Impacts Group, 2009). Ocean acidification is already impacting the aquaculture industry and is projected to continue to worsen. Commercial shellfish species suffer under conditions that are corrosive and decrease their ability to form, build, and maintain their shells. Shellfish farmers are already experiencing increased costs to deal with acidifying coastal waters and the increase in larval oyster mortality (Washington State Blue Ribbon Panel on Ocean Acidification, 2012).

Sea level rise may also negatively affect shellfish aquaculture by shifting habitat types and increasing water coverage of growing areas. This is a concern for shellfish growers, especially those that operate directly on intertidal substrate, as it may result in reduced access to shellfish beds, unless the beds move landward. If the shellfish beds remain in the same location, increased water coverage would reduce the time available for harvest as the beds would be submerged for a greater part of the day. If sea level rise causes beach profiles to shift landward, there is no guarantee that a grower will have access to the property with the preferred beach profile as it may shift off their property or leased area. This will become a property rights issue to be addressed as sea level rise occurs and intertidal areas shift (Climate Impacts Group, 2009).

The impact of climate change on the occurrence of HABs and the relationship to shellfish is discussed above. If HAB outbreaks increase as predicted due to climate change, there is the potential that commercial shellfish operations will experience more closures or restrictions to prevent human health impacts (Climate Impacts Group, 2009).

Transportation, navigation, and infrastructure

Ports and marinas will likely experience impacts to their infrastructure and operations due to sea level rise associated with climate change. Ports and marinas may need to adjust or reconstruct piers and structures to address sea level rise. Land-based port facilities may also be impacted by sea level rise and erosion and require adaptation to maintain full functioning of the facilities. The transportation systems that surround and support ports may also have negative consequences to their infrastructure that impact the port operations (Climate Impacts Group, 2009). Sediment loading from upstream erosion has the potential to affect ports and marinas by restricting boat access to and from the ocean. This may be overcome with increased dredging at additional effort and expense to the port (Industrial Economics Inc., 2014b).

Tribal uses

Tribal economies, traditions and treaties are heavily reliant on place-based natural resources. This makes them disproportionately susceptible to the negative consequences of climate change (P. Mote, 2015). In a study conducted through interviews with members of three Northwest tribes, Mote (2015) found that climate change may cause a shift in cultural traditions. Some aspects of tribal culture including songs, stories, prayers, and dances include natural resources that may be affected by climate changes. Additionally, the study found that seasonal changes due to climate change are impacting traditional activities as most are tied to an environmental cue rather than a specific date. This issue has become problematic and makes it challenging to rely on traditionally held information about cultural activities. However, all the tribes that participated in the study were continuing with their traditional cultural ways but had adapted with changes or alterations when necessary (P. Mote, 2015).

Economic impacts

The various uses of the MSP Study Area are likely to experience a range of economic impacts due to climate change. As discussed throughout this plan, the areas adjacent to the MSP Study Area receive great economic benefits from marine resources and the associated uses and industries. The combined effects of sea level rise, ocean acidification, and an increased likelihood of extreme weather events are likely to have very costly consequences for coastal systems and communities. Communities that are highly dependent on marine resources, like those adjacent to the MSP Study Area, are going to be challenged to adapt to a changing climate (Dalton et al., 2013). It is complex to consider quantifying the economic impacts of climate change in and adjacent to the MSP Study Area. A few examples of potential economic impacts are included in this section.

Coastal uses that rely on shellfish populations are especially vulnerable to climate change and particularly the impacts of ocean acidification. Washington is the country's leading producer of farmed oysters, clams, and mussels with total annual farmed shellfish sales of over $107 million. Shellfish growers in Washington directly or indirectly employ more than 3,200 people (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). In addition to the aquaculture industry, ocean acidification threatens recreational shellfish harvesting and the economic benefits that brings to coastal communities. Recreational clam and oyster harvests account for $27 million in annual impacts to coastal economies as well as $3 million in state revenue from licensing (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). One grower has moved hatchery operations to Hawaii to avoid the impacts of ocean acidification on the oyster larvae. The associated costs are obviously great and not all growers will have the means to relocate hatcheries. For growers that do not own a hatchery, but purchase oyster spat, they will still likely face increased costs passed down from hatchery owners (Taylor et al., 2015). Shellfish growers may also experience economic impacts as a result of sea level rise. As discussed above, additional water coverage of growing areas will decrease harvest time available and reduce workdays for growers (Taylor et al., 2015).

Increasing HABs will likely lead to an increase in recreational and commercial shellfish fishery closures. This would reduce or eliminate related visitor spending during the closures. Dyson and Huppert (2010), conducted a study to measure the changes in the local economy of Pacific and Grays Harbor counties due to reduced visitor expenditures during HAB closures of recreational shellfish fisheries. They found that a single beach closure for an average opening (typically 2-5 days) of all beaches to be an expenditure reduction of $4 million dollars (2008 dollars) and for a whole season closure (October through April) to be an expenditure reduction of $20.4 million dollars (2008 dollars) (Dyson & Huppert, 2010). Although the impacts of a HAB closure may be more complex than this as tourists may shift their vacation to a different coastal community or alter their spending in some other way, it does indicate that HABs could have a significant economic impact on coastal communities (Dyson & Huppert, 2010).

Commercial and recreational fisheries are also predicted to experience economic consequences of climate change. The specific effects are challenging to assess though, as different species will vary in their responses to climate change with changes in distribution, abundance, and productivity. This will in turn impact the level, composition, and value of landings (Dalton et al., 2013). Dungeness crab and pink shrimp are both expected to be affected by ocean acidification. Dungeness crab is one of the main commercial fisheries in Washington, providing the highest ex-vessel value per weight landed, so the economic impacts could be severe. Salmon fisheries could also be impacted as water temperatures increase and become inhospitable to species that prefer cooler water (Taylor et al., 2015).

Summary

Climate change and the resulting shifts in oceanic and atmospheric conditions are likely to have widespread impacts on the MSP Study Area. Scientists predict that climate change will bring changes in air temperature, precipitation, water temperature, sea level, ocean pH, storminess, harmful algal blooms, and hypoxia. However, it becomes more challenging to accurately predict the magnitude of the impacts as it depends on the interplay of many different factors. The economy of the coastal areas adjacent to the MSP Study Area is highly influenced by the ocean economy and likely to experience impacts due to climate change.

As climate change continues and the impacts are felt throughout the MSP Study Area and beyond, this may influence the demand for new ocean uses addressed in this MSP. New uses may be seen as a way to offset the impacts of climate change. Offshore renewable energy could be one method of meeting increasing energy demands while decreasing emissions of greenhouse gases. Offshore aquaculture may be used to address climate change impacts on shore-based aquaculture. Dredge disposal and sand and gravel mining may be used to address erosion issues along the shoreline through beach restoration. The effects of climate change on the ecological and human communities and existing uses of the MSP Study Area will need to be considered and addressed as any new uses for the area are considered.

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