Chapter 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 of Washington's ocean uses. The health and status of the MSP 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 MSP 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 section 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 not only to understand the ecological context of Washington's ocean and estuaries, but also to consider potential future new uses and how they may affect the ecological status of the MSP 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

The currents, tides, eddies, plumes, upwelling, and other physical features of Washington's Pacific 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 Washington's Pacific coast) is predominantly influenced by large-scale ocean processes that exhibit seasonal patterns and a highly dynamic ocean environment (B. M. 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) depending upon its source waters, including the Pacific Subarctic, North Pacific Central, and Southern water masses (B. M. 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 (B. M. Hickey & Banas, 2003, 2008; Pirhalla et al., 2009). The PNW has an upwelling/downwelling seasonal pattern driven by wind direction. Upwelling occurs mostly during the spring and summer when the wind comes from the north,

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

but with important 'conditioning' events occurring in the winter (Black et al., 2011). Upwelling is the process by which currents and wind stress from the north combine with the Coriolis force to push surface water offshore and replace it with deep, cold, highly saline, and nutrient-rich water from below (Figure 2.1-1). Upwelling brings nutrients up into the upper portion of the water column where sunlight penetrates, known as the photic zone. These 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 during the spring and summer (Andrews, Harvey, & Levin, 2013; B. M. Hickey & Banas, 2003, 2008; Pirhalla et al., 2009).

The seasonal pattern generally transitions to downwelling during the fall, which persists throughout winter. During downwelling, currents and wind stress from the south push water onshore. This water is typically warmer, less saline, and less nutrient-rich (B. M. Hickey & Banas, 2003). Seasonal upwelling and downwelling events can be detected by analyzing parameters such as sea surface height and chlorophyll-a concentration (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).

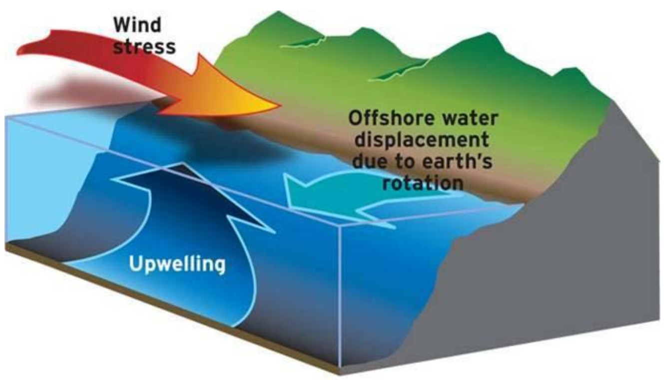

Figure 2.1-1. Schematic of upwelling forces. Source: (NOAA Fisheries, n.d.-a).

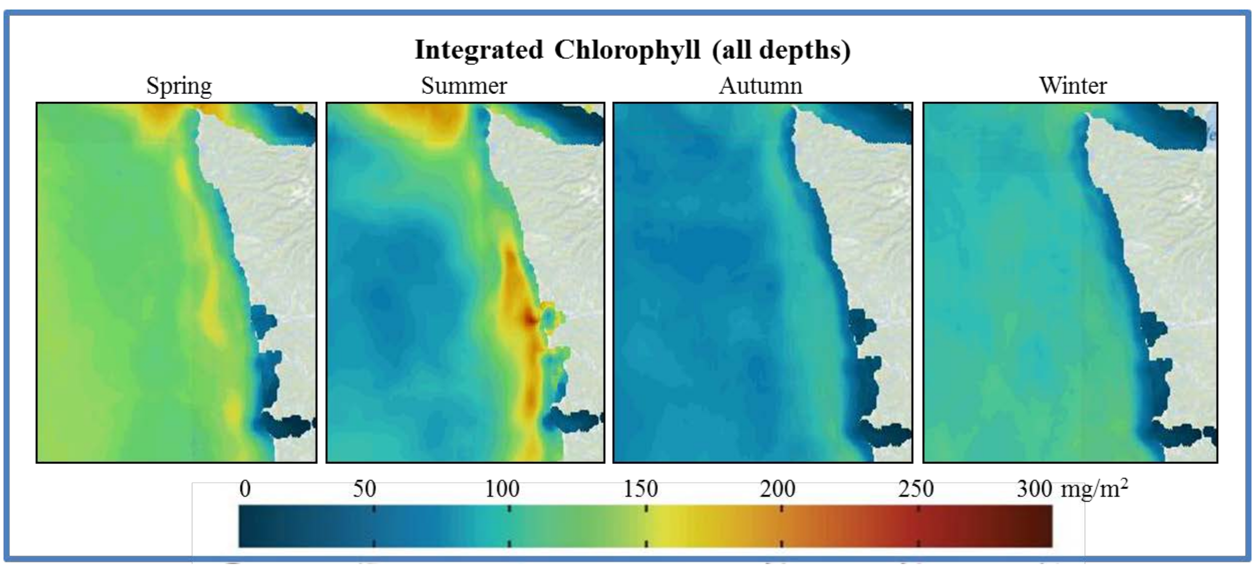

Figure 2.1-2. Integrated chlorophyll (all depths) for 2005-2006. Source: (B. Hickey, Banas, & MacCready, 2013) at http://msp.wa.gov/msp-projects/ocean-conditions/#Chlorophyll.

In addition to upwelling, other features influence ocean and coastal productivity along the Washington coast. A significant element is the Juan de Fuca Eddy, a semi-permanent feature located off the coasts of northern Washington and southern Vancouver Island in 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 nutrient content, increased productivity and retention, and enhanced higher trophic-level biomass (Andrews et al., 2013; B. M. Hickey & Banas, 2008).

The Columbia River Plume is another major feature that influences productivity along Washington's Pacific coast. The river plume brings fresh water, 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; B. M. Hickey & Banas, 2008). While the Columbia River Plume generally provides fewer nutrients to the ocean during the summer months, some research suggests the plume may help sustain local ecosystems by providing a nutrient supply during periods of weak to no upwelling or during late spring transitions (B. M. Hickey & Banas, 2008).

Coastal trapped waves, another important physical process and feature in the Study Area, are a complex interaction of shelf slope, wind, and angular momentum. They can accelerate local longshore currents. Coastal trapped waves can generate as far south as central California (B. M. 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 relatively higher productivity of the Washington coast as compared to the rest of the PNW (southern Oregon and northern California) (B. M. Hickey & Banas, 2008). See Figure 2.1-3.

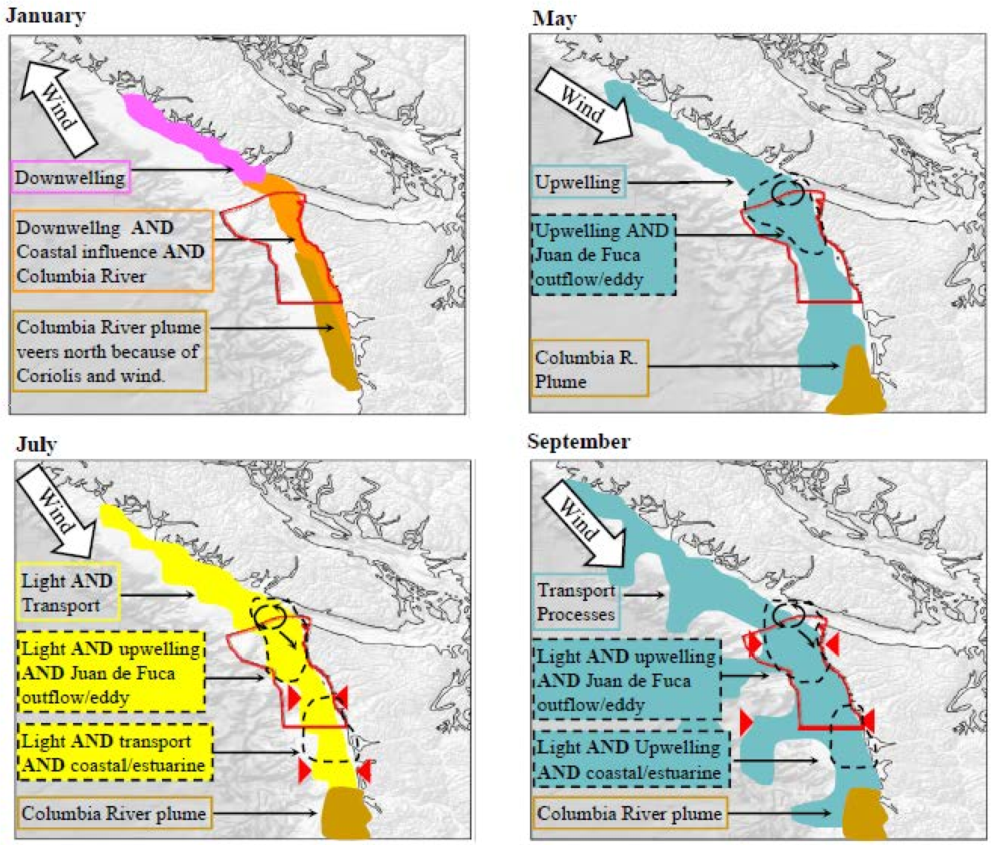

Figure 2.1-3. Schematic of general physical factors limiting nutrient availability and surface response during January, May, July, and September. Source: Pirhalla et al., 2009.

Estuaries

Several estuaries occur within the MSP Study Area. Estuaries in the northern portion of the MSP Study Area are relatively small outlets from coastal rivers. Two large estuaries in the southern portion of the MSP Study Area, Grays Harbor and Willapa Bay, are significant features of the southern coast.[2] 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 (B. M. 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 (B. M. Hickey & Banas, 2003). During periods of downwelling, the Columbia River Plume enters both Willapa Bay and Grays Harbor estuaries (Banas, Hickey, MacCready, & Newton, 2004). In the large estuaries within the MSP Study Area, upwelling rather than riverflow is the primary source of estuarine nutrients and primary production (Banas et al., 2004).

[2] The estuary at the Mouth of the Columbia River is not included within the MSP Study Area.

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 minimize physical stresses (high temperature, desiccation, etc.) on the tidal flats. Low tides in the winter can cause freezing and increased mortality of exposed organisms (B. M. 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 influential on the various organisms occupying different tidal zones, mudflats, rocky shores, and other communities (Andrews et al., 2013).

Climate and Large-scale Influences

Washington's Pacific coast 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 estuaries. Storms during the winter months also play an important role in shaping the physical environment (B. M. Hickey & Banas, 2003; Pirhalla et al., 2009; Skewgar & Pearson, 2011).

Large-scale, global processes influence weather from year to year and affect climate on an interdecadal scale. These large-scale climatic processes interact in complex ways and significantly influence 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).

In the northeast Pacific Ocean, 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 that do not normally frequent this range, and an elevated average water level. During a cold phase, sometimes referred to as La Niña, the opposite will occur (I. M. Miller, Shishido, Antrim, & Bowlby, 2013; Moore, Mantua, Hickey, & Trainer, 2010). During an El Niño phase, storms, large waves heights, and wave angles have also been documented creating erosion hotspots in the PNW (Ruggiero et al., 2013).

The Pacific Decadal Oscillation (PDO) also influences sea surface temperature and sea level (Pirhalla et al., 2009). In the northeast Pacific, PDO positive phases cause warm temperatures, positive sea level pressure, and higher sea level (I. M. Miller et al., 2013). The PDO is a climatic recurring event and studies have shown that marine fisheries abundances vary over these time series (Mantua, Hare, Zhang, Wallace, & Francis, 1997). During a positive PDO phase, decreases in production in salmon stocks in Washington, Oregon, and California are observed. During a negative PDO phase the salmon stocks experience high production in the same areas (Mantua & Hare, 2002; Mantua et al., 1997; Parson, Mote, Hamlet, Keeton, & Lettenmaier, 2003). PDO and ENSO occur on different time scales, but positive phases of ENSO tend to be associated with positive phases of PDO. A typical ENSO event will last for 6-18 months and a typical PDO event will last for 20-30 years (Mantua & Hare, 2002; Moore et al., 2010).

Another large-scale process, the Blob (aka North Pacific Mode or marine heat wave), has influenced sea surface temperature in the MSP Study Area. In 2013-2015, the Blob caused exceptionally warmer waters off the West Coast (Kintisch, 2015), and may have influenced marine species ranges and ocean productivity (Bond, Cronin, Freeland, & Mantua, 2015; Hartmann, 2015; Kintisch, 2015). The Blob is believed to have resulted from a high-pressure atmospheric ridge (Kintisch, 2015).

Storms and Wave Energy

The PNW is known for its severe waves, 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. Winter months (November through February) are characterized by high, long-period waves with a west southwest approach, 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).

Increases in wave height and storm intensity have been observed in the PNW over the last half of the 20th century (Ruggiero et al., 2013). The frequency of strong storms has also 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, accretion, sediment transportation, surf zone energy, and flooding. While storm and wave energy impact the entire PNW coast, the sandy beaches, dunes, and bluffs of the southwestern coast of Washington are particularly vulnerable to erosion. Major episodes of erosion often occur during storm events, and this will be exacerbated by increased storm strength or frequency (Climate Impacts Group, 2009).

Water Quality

Water quality is important for species, habitats, and human health. Several 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 and toxins.

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 Environmental Protection Agency’s implementing regulations. The Washington State Department of Health (DOH) 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 these standards are met.

For Ecology's water quality assessment, all available and credible water quality and fish tissue data[3] are assessed. Waterbody segments are evaluated and categorized using 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 standards for pollutants tested
- 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 total maximum daily load (TMDL)
    - Category 4a: polluted waters with an approved total maximum daily load
    - Category 4b: polluted waters with an approved water quality improvement plan that is equivalent to a TMDL
    - Category 4c: 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. Category 5 waterbody segments will need a TMDL, pollution control program, or other actions to reach compliance with water quality standards.

TMDLs or other water quality improvement projects are a management approach to cleaning up 303(d)-listed (polluted) waterbodies so that they meet state water quality standards. Water quality improvement plans allocate pollutant discharges to point and nonpoint 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, which 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 federal Environmental Protection Agency (EPA) approved the current water quality assessment 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 by Ecology, other state agencies, and various organizations. The four coastal treaty tribes also monitor water quality in their respective U&As,[4] particularly for HABs and recreational beach safety. The following are summaries of the main water quality considerations within the MSP Study Area.

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

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

Dissolved Oxygen

Dissolved oxygen in the water is essential for all aerobic marine and estuarine life. Dissolved oxygen levels are primarily influenced by the water's temperature, gas exchange with the atmosphere, and source. Dissolved oxygen can decline in waters with high levels of respiration, 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 (a state of low dissolved oxygen concentration) in Washington shelf and coastal waters is related to upwelling. Upwelling delivers oxygen-depleted water from the bottom up to the surface, periodically causing hypoxic or even anoxic (no oxygen) conditions (Office of National Marine Sanctuaries, 2008). The nutrients delivered by upwelling can induce algal blooms, leading to increased quantities of sinking organic matter. This matter is then respired which further depletes oxygen (Rabalais et al., 2010). Along the upper continental slope, the layer of deep water 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 layer, which is already normally hypoxic, 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 the 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 Oregon's shelf waters has been increasing since 2000. 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. Other segments towards the southern part of the bay near the mouth of the Naselle River and just west of Long Island are listed as Category 2 (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 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 (Andrews et al., 2013). The over-enrichment of water by nutrients can lead to eutrophication, which causes enhanced primary productivity and increased algal blooms. When this happens, much of this organic matter then descends into bottom waters, which leads to increased microbial activity and decreased dissolved oxygen (Diaz & Rosenberg, 2008). The resulting decrease in dissolved oxygen can cause mortality of fish and invertebrates. Nutrient concentrations can vary between locations 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 nonpoint 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. This is due to upwelling of nutrient-rich water, as well as the Juan de Fuca outflow and Columbia River Plume, which drive the high productivity along the coast (B. M. Hickey & Banas, 2003). While the northern coast of Washington does not have significant population centers, the southern coast does have greater human pressures that could lead to increases in nutrients through point or nonpoint sources. However, 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 (B. M. 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). 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

Carbon dioxide (CO_2) dissolved in seawater decreases the pH of the water, making the ocean more acidic. This results in a corrosive environment for some shell-forming organisms. The decline in pH is known as ocean acidification.[5] 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 that contribute to ocean acidification include increased nutrient inputs. These inputs can increase algal blooms, and in turn, increase the decomposition of organic matter when the algae die, thereby 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).

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 many marine species use in shell and exoskeleton formation. When the saturation state is lowered, it can become more

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

difficult for shell-forming organisms such as oysters, crabs, corals, pteropods, and phytoplankton to build the shells necessary for their survival (Feely et al., 2012). Studies have also shown a range of impacts from ocean acidification on fish larva development, behavior, tissue and organ structure, otoliths, olfaction, and egg survival (Stiasny et al., 2016). 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. PNW oyster hatcheries raising oyster larvae experienced mass mortalities 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 used monitoring equipment and pH buffering to adapt to 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).

Recent laboratory experiments have found that Dungeness Crab larvae experience slower development and decreased survival with decreasing pH. This would likely have population-scale impacts and could potentially cause a decline in the fishery (J. J. Miller, Maher, Bohaboy, Friedman, & McElhany, 2016).

Scientists anticipate that ocean acidification and associated effects will increase in the future, causing more challenges for the recreational and commercial fishing industries and resulting in unknown effects to PNW species, habitats, and ecosystems. 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 responses 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. The diatoms of *Pseudo-nitzschia spp*. can produce the neurotoxin domoic acid, which causes amnesic shellfish poisoning. The dinoflagellate *Alexandrium cantenella* produces the neurotoxin saxitoxin, which causes paralytic shellfish poisoning, and the dinoflagellates of *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; Washington State Department of Health, n.d.-b).

Harmful algal blooms (HABs) occur when levels of phytoplankton with toxins reach a particular threshold. Shellfish that filter the toxic phytoplankton, such as clams and mussels, can concentrate the toxins and expose human consumers to harmful levels. Safety levels for toxins in shellfish are set by the Food and Drug Administration (FDA).

The Olympic Region Harmful Algal Blooms Partnership (ORHAB) and coastal tribes cooperating with ORHAB, such as Quileute and Makah, regularly monitor phytoplankton levels in water and toxin levels in both water and in shellfish tissue. The partnership is coordinated by the Olympic National Resources Center and consists of the Washington State Department of Health, Washington Department of Fish and Wildlife, the Quinault Indian Nation, and others. The Quileute Tribe operates with separate funding and sends samples to DOH; results are posted through WDFW.

When toxin concentrations reach a particular threshold, the harvest of affected shellfish is restricted. State beaches have been closed to shellfish harvest and marine waters have been closed to recreational and commercial crab fishing to protect human health (Olympic Regional Harmful Algal Bloom Partnership, 2015; Washington State Department of Fish and Wildlife, 2015b). DOH publishes a recreational shellfish safety map and list of public beaches and their status online. They also post warning signs at beaches, maintain a hotline for beach closure information, and provide similar information for commercial shellfish growers (Washington State Department of Health, n.d.-a). The Quileute Tribe posts advisories about high levels of HAB for its members on its website, on a hotline, and at trailheads for shoreline access.

The occurrence of HABs on the coast is considered 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. This contaminates shellfish harvest beaches, with higher toxin levels in the northern portion of the Study Area generally occurring during summer and fall. Southern Washington 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 (B. M. Hickey et al., 2013). The Columbia River Plume may act as a HAB barrier for southern Washington beaches during the summer and fall, which can prevent accumulation of toxins in shellfish. But, it may also act as a HAB conduit during winter and spring, resulting in shellfish closures (B. M. 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 due to dams and water removals, as well as climate-related phenomena (Office of National Marine Sanctuaries, 2008). In 2015, the U.S. 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, referred to as the Blob, are thought to have contributed to this massive HAB (Doughton, 2015).

Chemical Contaminants

Chemical contaminants such as metals, persistent organic pollutants, hydrocarbons, and PCBs are also potential pollutants that can affect the health of marine waters. At present levels, these pollutants are not a concern within the waters of the Olympic Coast National Marine Sanctuary (OCNMS), 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. 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, 2016a).

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. The river valley is dominated by agriculture, with the surrounding area mostly used for forestry. Willapa Bay is monitored for contaminants, including several pesticides and other pollutants. Chrysene, a compound from creosote used for preserving wood, as well as the polycyclic aromatic hydrocarbons Benzo(a)anthracene and Benzo(b)fluoranthene 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, 2016a).

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, vessel discharge,[6] and from livestock, pets, wildlife, and humans. As bacteria levels increase, so does the risk of human illness. 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 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,[7] 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 DOH to close two sections of the Mocrocks Razor Clam beach in the summer beginning in 2011. 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, 2016a). 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 are 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.

[6] Vessel discharges as a source of pollution are discussed below in the Stressors section.
[7] There is no public access north of the Moclips River. Commercial harvest of Razor Clams is conducted by the Quinault Indian Nation.

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 in the Bay at the mouth of and including the lower part of the Willapa River because of the wastewater treatment plant (WWTP). Commercial shellfish harvest is also prohibited in an area at Bay Center because of high fecal coliform samples in that area (Office of Environmental Health and Safety, 2015). Recent construction of a regional wastewater treatment plant and closure of the South Bend and Raymond sewage treatment plants are 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 8ºC to 16ºC (46ºF to 61ºF) annually. Sea surface temperature varies across the shelf (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 the El Niño-Southern Oscillation and the Pacific Decadal Oscillation. In recent years, warm temperature anomalies ranging from 1ºC to 4ºC (2ºF to 7ºF) have been observed (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 (B. M. 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 temperature increases (Washington State Department of Ecology, 2012a).

Geomorphology

Washington's coast is located in a tectonically active region, in which the Juan de Fuca oceanic plate is subducting under the North American continental plate. This 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 MSP 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 (aka North Beach Peninsula), which consists mostly of the barrier spit separating Willapa Bay from the Pacific Ocean, is about 28 miles long. The low-lying central and southern portion of Washington's Pacific coast is vulnerable to rising sea level with the potential for increased coastal inundation, erosion, flooding, and higher tidal and storm surge (Snover, Mauger, Whitely Binder, Krosby, & Tohver, 2013).

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 (aka Washaway Beach). 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 and slope progressively widen to the north, ranging from 15 nm to 78 nm in width. The 330 foot water-depth contour occurs fairly close to shore, usually within 22 nm (Minerals Management Service, 2007). 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 coast from northernmost end of the MSP Study Area south to the Hoh River consists largely of 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 data for the MSP 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). Some seafloor mapping projects undertaken in the MSP Study Area include the Washington State Outer Coast Seafloor Atlas of the OCNMS,[8] and a 2011 lidar coastal survey by the U.S. Army Corps of Engineers National Coastal Mapping Program.[9]

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 that 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. The most important management issues identified for these areas by participants were ecosystem based management, living resource management, coastal inundation & natural coastal hazards, "other regulatory" issues, 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 MSP 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 (B. M. 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 where massive submarine landslides occur 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 (B. M. 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 and contribute to the high productivity of Washington's ocean waters (B. M. Hickey & Banas, 2008).

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[8] Available at http://olympiccoast.noaa.gov/science/habitatmapping/habitatmapping.html

[9] Available at https://catalog.data.gov/dataset/washington-2011-lidar-coverage-usace-national-coastal-mapping-program

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 earthquake with an approximate magnitude of 9.0 on the Richter scale 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 Oregon and northern California coasts (Goldfinger et al., 2012).

The next great CSZ earthquake is anticipated to have a magnitude from 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 earthquake in Tohoku, Japan and the 2010 magnitude 8.8 earthquake in Maule, Chile (Cascadia Region Earthquake Workgroup, 2013).

Biology

MSP Study Area waters have high biological productivity and support a variety of habitats and species, many of which are important ecologically, culturally, and economically to Washington, the United States, and the world.[10] Habitats are where organisms live, eat, shelter, and reproduce. A living ecosystem is a 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 Washington's Pacific coast and to emphasize the importance of protecting these biological resources now and in 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 these 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.

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

- 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.

Habitats

Several habitats occur within the MSP Study Area. For the purposes of this MSP, six major habitat types are described: pelagic, seafloor, kelp forests, rocky shores, sandy beaches, and large coastal estuaries. These habitat categories were chosen by the National Marine Fisheries Service Northwest Fisheries Science Center for the ecological indicators and the ecological status and trends reports produced for the MSP (Andrews, Coyle, & Harvey, 2015; Andrews et al., 2013). They 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).

Pelagic habitat

The pelagic zone represents all water column habitat from the surface to near-bottom in MSP Study Area waters. Physical drivers important to 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).

Zooplankton are key links in the food chain, connecting primary production to upper trophic levels.[11] Many zooplankton migrate vertically in the water column from near the seafloor to the surface to feed on phytoplankton. Shifts in zooplankton species composition can be correlated with regional climate and seasonal patterns. Copepods can be categorized based on their affinity for water type. Cold water copepods tend to be lipid-rich, providing a key energy source to pelagic fish, while warm water copepods have a lower lipid concentration and can be a lower quality food source. Cold water species typically dominate the zooplankton community

[11] Trophic levels refer to a class of organisms that occupy the same position in a food chain. Primary production is the bottom of the food chain, typically made of plants (e.g. phytoplankton). Primary consumers are those organisms that eat those plants (e.g. zooplankton) and secondary consumers eat primary consumers (e.g. fishthat eat zooplankton), etc. Upper trophic levels refer to organisms that are higher up on the food chain.

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).

Pteropods can serve as an indicator for ocean acidification because they are experiencing shell dissolution as acidification increases, and they are a key food source for herring, mackerel, salmon, and other fish species (Chan et al., 2016). Gelatinous zooplankton are also an important part of the pelagic food web. Jellyfish compete with forage fish and juvenile salmon for similar food items, so changes in jellyfish abundance can impact community structure (Andrews et al., 2015).

The pelagic zone provides important habitat and food for a variety of fish. Forage fish species, including smelt, Pacific Herring (*Clupea pallasii*), Northern Anchovy (*Engraulis mordax*), and Pacific Sardine (*Sardinops sagax*), live and feed in the upper pelagic zone. They act as 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 those consumed by salmon, rockfish, and other groundfish species (Andrews et al., 2013). Myctophids (a.k.a. lanternfish) may be the most abundant pelagic family of fish. Like many zooplankton, they occupy deeper waters during the day and rise to feed on phytoplankton at night, 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 in 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 fish (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).

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

Seafloor habitat

Seafloor habitat includes all bottom habitats in water up to 30 m (98 feet) in depth in the MSP Study Area.[12] 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

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

Area, with fish and invertebrates congregating in these areas. While the entire MSP Study Area has not been surveyed to date, within the Study Area 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. However, 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 of the seafloor habitat food web, as they are a large portion of the diet of 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 such as 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 invertebrates and other fish. Commercial fishing activity from bottom trawl and other gear may interact with the seafloor and cause damage, particularly to high relief or hard substrate areas.

Low dissolved oxygen events (hypoxia and anoxia) are physical stressors to seafloor habitat. These events can cause stress to 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). Hypoxia impacts are expected to grow rapidly in intensity and extent over the coming decades (Chan et al., 2016). For more information, please see the Dissolved Oxygen section.

Kelp forests

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 with patchy areas in the central coast and estuaries (Map 4) (Andrews et al., 2015).

Kelp forests form diverse communities and provide 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 fish, especially rockfish, sculpins, greenling, lingcod, perch, juvenile salmon and others, including many fish on Washington's list of Species of Concern.[13] Floating kelp provides 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 provide important information about 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 sensitive to increases in water temperature and the availability of nutrients. Light penetration is also an important physical factor, and increased sediment runoff due to events like 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 graze upon kelp in Washington: red (*Mesocentrotus franciscanus*), purple (*Strongylocentrotus purpuratus*), and green (*S. droebachiensis*). Sea urchin abundance is controlled by predation, and the most notable predators of sea urchins are sea otters, sea stars, 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 (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). Sea otters also prey on other shellfish including commercially and recreationally valued species such as clams and crab (Lance, Richardson, & Allen, 2004).

Existing human pressures for kelp forest habitat identified in the ecological indicators report for the MSP include recreational fishing, pollutants, and excess nutrient inputs (Andrews

[13] A current list of Species of Concern is available on WDFW's website, at http://wdfw.wa.gov/conservation/endangered/.

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 (Airoldi, 2003; Shaffer & Parks, 1994).

Rocky shores

The rocky shores habitat category 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 including bedrock, boulder fields, and cobble and gravel. Tide pools, boulder size, and proximity to sand can influence the communities within this habitat (Andrews et al., 2013).

Variations in substrate types, 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 (e.g. macroalgae, surfgrass) 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, and other factors like competition and predation. Suspension feeders provide habitat for macroalgae, invertebrates, and fish. They can influence nutrient concentrations in intertidal waters and provide food for predators including humans (Andrews et al., 2013).

Dozens of grazing invertebrates inhabit 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 (Andrews et al., 2013). Prevalent suspension feeders in the rocky shores include barnacles and mussels that feed on phytoplankton and detritus (Andrews et al., 2015). Predators within rocky shore habitat include the ochre sea star (*Pisaster ochraceus*), whelks, anemones, worms, and crabs. Predators on rocky shores also exhibit zonation and microhabitat preferences (Andrews et al., 2013).

Pisaster is considered a keystone predator and its presence helps maintain the diversity of intertidal rocky communities (Andrews et al., 2013). Sea star wasting disease (SSWD) devastated over 20 species of sea stars from Mexico to Alaska in 2013 and 2014 (Eisenlord et al., 2016). SSWD has been linked to a densovirus, and disease progression and mortality rates may have been increased by warm temperature anomalies. In Washington, monitoring showed high mortality rates in 2014 and continued levels of wasting in survivors in 2015 (Eisenlord et al., 2016). Larger sea stars were more likely to be observed with the disease and to experience greater reductions in abundance. As a keystone species, the shift in population to smaller individuals could have lasting impacts on population recovery and the composition of rocky intertidal communities (Eisenlord et al., 2016).

Several fish 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 also 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. Bald Eagles prey on adults, chicks, and eggs at seabird colonies. This activity has likely contributed to population declines in Common Murres (*Uria aalge*) and Glaucous-winged Gulls (*Larus glaurescens*).

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 rocky shore habitat. The intertidal zone is defined by 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 has also been 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).

There are several existing pressures that could impact the health of rocky shores. Specific activities include trampling and harvest by human visitors and competition from non-native species. An additional pressure is 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 include sediment deposition, wave energy, beach slope, upwelling, and climate variability. Upwelling provides nutrients and food to 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 also recycle ammonium into the nearshore water, promoting primary production. Other invertebrate macrofauna within Washington's sandy beach habitat include 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 provides 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. The 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 beaches, which are characterized by features such as steep slopes, coarser sand, and a lack of surf zones (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 adjacent forested cliffs, or have 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 mouth of the Columbia, 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.[14] They are also important transitional systems that are linked to freshwater, terrestrial, and marine processes. In particular,

[14] Ecosystem services describes the types of benefits humans receive from functioning ecosystems. Examples of ecosystem services include providing food and clean water; controlling climate and disease; and supporting primary production and nutrient cycling.

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 are intertidal (B. M. 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 diatoms, 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 being 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 in the estuaries. Specific shellfish species include the Olympia Oyster (*Ostrea lurida*),[15] non-native Pacific Oyster (*Crassostrea gigas*), non-native Manila Clam (*Venerupis philippinarum*), and Dungeness Crab. Numerous listed and commercially important fish 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 the juveniles of many species of fish and crabs. Pacific Herring spawn in Willapa Bay and Grays Harbor (Washington State Department of Fish and Wildlife, 2017a). Many studies have confirmed that juvenile salmon use estuaries as a source of food and refuge from predators, and have detailed the spatial and temporal differences between populations (Hughes et al., 2014; Sandell, Fletcher, McAninch, & Wait, 2013; Simenstad, Fresh, & Salo, 1982).

Dungeness Crab are also known to rely extensively on estuaries as habitat for juveniles (Gunderson, Armstrong, Shi, & McConnaughey, 1990; Hughes et al., 2014) Estuaries are also important foraging areas for visiting wildlife such as migratory shorebirds, ducks, and geese, as well as terrestrial animals like deer and elk. Harbor seals also reside within coastal estuaries. Seals haul out on rocks, reefs, beaches, and docks, and feed on invertebrates and fish 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). Eelgrass beds perform a primary production role in the nearshore food web. They create a physical habitat that provides three-dimensional structure to otherwise bare mudflats, slows water currents,

[15] The Olympia Oyster is also a Washington State Candidate Species on the Species of Concern List.

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.

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). Eelgrass 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 at some point in their life-cycle, such as Dungeness Crab, Pacific Herring, salmonids, shrimp, and flatfish (Skewgar & Pearson, 2011).

The presence of non-native eelgrass can impact the estuarine system. *Z. japonica* colonizes unoccupied mudflats and converts them to vegetated habitat (J. L. Ruesink et al., 2010; Shafer, Kaldy, & Gaeckle, 2014). Direct competition between *Z. marina* and *Z. japonica* is often limited due to their ranges. *Z. marina* is typically found in high subtidal to low intertidal zones while *Z. japonica* is typically found in mid- to high intertidal zones (Mach, Wyllie-Echeverria, & Chan, 2014; Shafer et al., 2014).

Studies designed to assess the ecological impacts of non-native *Z. japonica* are limited, but have found both positive and negative outcomes (Mach et al., 2014). Shellfish growers are concerned about the impacts of the non-native eelgrass on clam and oyster species important to aquaculture. One study on commercial clam farms in Willapa Bay found that *Z. japonica* impacted Manila Clam growth. The study showed decreased growth rates in study plots with *Z. japonica* and greater growth rates where it was removed. In 4 out of 5 commercial clam farms studied, productivity was greater where *Z. japonica* was removed than where it was left untreated (Patten, 2014).

Oysters also create a three-dimensional biogenic habitat in the lower intertidal and subtidal zones. Fish and invertebrates live within accumulations of oyster shell, and the oysters provide ecosystem functions by circulating and clarifying water, reducing hypoxia, and filtering nutrients. Historically, Willapa Bay supported large populations of Olympia Oysters in the low intertidal zone and the shallow subtidal zone, but they may have been uncommon in Grays Harbor (Baker, 1995; Cook, Shaffer, Dumbauld, & Kauffman, 2000). Overharvest and habitat loss led to commercial extinction of the Olympia Oyster by 1930. Recovery has been hindered by the removal of shell accumulations (the preferred habitat of Olympia Oyster larvae) and the expansion of eelgrass beds. Recent aquaculture has focused on the non-native Pacific Oyster (Blake & Zu Ermgassen, 2015; J. Ruesink et al., 2005; Skewgar & Pearson, 2011).

Many human pressures currently exist within Washington’s large coastal estuaries including fishing, dredging, shellfish aquaculture, non-native species, watershed activities, port development, and commercial shipping. Pollution is another pressure, including both pollution of a physical nature like suspended sediment and temperature increases, as well as chemical pollution including but not limited to acidification (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. For example, in Willapa Bay about 30% of the tidal marshes between high and extreme high water have been diked and converted to agricultural or developed land, and sediment loads have been altered by logging and damming on the Columbia River. In addition, 45 introduced marine species have been documented, and the Olympia Oyster became commercially extinct due overexploitation and habitat loss (J. L. Ruesink et al., 2006).

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, estuaries are known to be vital habitat for many commercially and recreationally valuable species, wildlife, and endangered and threatened species, many of which support key human uses. As a result, the state considers Willapa Bay and Grays Harbor estuaries to be Ecologically Important Areas. See Section 3.2 for more information on the Ecologically Important Areas analysis and Section 4.3 for recommendations related specifically to estuaries and resources within them.

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 key fish, 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.

Fish

The MSP Study Area is habitat for a variety of fish. Fish are important both ecologically and economically to the state of Washington. Key groups of fish discussed here are pelagic fish, groundfish, and salmonids and other anadromous fish.[16] Map 5 shows the results of the Ecologically Important Areas (EIA) analysis for fish species.[17]

Forage fish, migratory species, and pelagic fish

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).

[16] Information on fishing is available in Section 2.4: State and Tribal Fisheries.
[17] Details of the EIA analysis, data sources, and maps are provided in Section 3.2: Ecologically Important Areas Analysis.

Table 2.1-1. Forage fish species

Common Name	Scientific 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 the Common Thresher Shark and Albacore Tuna. These species feed at a variety of levels on the food chain, ranging from plankton to fish or mammals. Migratory species are important state 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 subject to pressures including those from fishing, pollution, and climate variations. These variations can include upwelling and influences from source waters, as well as El Niño/La Niña events and the impacts they have on prey availability and habitat (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 refers to a group of numerous species, with 30 species identified by NOAA in the waters of the Study Area. Over 15 species of flatfish have been identified in Sanctuary 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 is a human pressure that has affected groundfish. Several species have been subject to overfishing, especially during the 1980s and 1990s (Pacific Fishery Management Council, 2014a). Some rockfish species, like Yelloweye Rockfish, are particularly sensitive to fishing pressure because they are long-lived and exhibit low productivity life history characteristics. A few stocks of rockfish within MSP Study Area waters have been declared overfished since 2000. However, 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. At the time of publication, they are being reconsidered by the Pacific Fishery Management Council (PFMC) in several areas within the MSP Study Area to protect habitat and aid in stock recovery. NOAA Fisheries, tribes, and state fisheries management agencies monitor and assess the status of groundfish populations. However, there are data gaps in the monitoring of rockfish populations due to the difficulty and cost of conducting routine, scientific surveys in rocky reef habitats. These habitats are difficult or not possible to access with the bottom trawl gear used for stock assessments.

Salmon and other anadromous fish

Salmonids (salmon and related species) and other anadromous fish 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, and then return to home rivers, streams, and lakes upon maturity to start the cycle again. Eight species of salmonids, Pacific Eulachon, Green Sturgeon, White Sturgeon, and Pacific Lamprey spend some portion of their life within the MSP Study Area (Table 2.1-2). Note that species occurrence can vary by year due to changing ocean conditions and other environmental factors. American Shad is a non-native anadromous species that was introduced to the West Coast in the late 1800s and has thrived in the region. Nine of the thirteen anadromous species in the MSP Study Area are listed under the federal Endangered Species Act (ESA) or on the Washington State Species of Concern lists (Washington State Department of Fish and Wildlife, 2017b).

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 including fishing, loss of freshwater habitat, hydropower dams, land use activities, predation, and poor ocean conditions, which collectively can include changes in chemical or physical conditions and an accompanying loss of food supply (NOAA Fisheries, 2014b). Salmonids are considered for listing and recovery under the ESA by distinct populations known as evolutionarily significant units (ESUs).

Several listed ESUs (e.g. Puget Sound Chinook) and non-listed ESUs (e.g. Washington Coast Chinook) spend some or all of their adult lives in the MSP Study Area. Under the ESA, critical habitat is designated for certain salmon ESUs in streams, rivers, and some bays or estuaries adjacent to the Study Area. Under the Magnuson-Stevens Act, Essential Fish Habitat has been designated for marine salmon (Chinook and Coho Salmon) for the entire EEZ. For Pink Salmon, Essential Fish Habitat has been designated in Puget Sound and the Strait of Juan de Fuca, and extends into the Study Area. (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 dates, 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 efforts, and fisheries management (Washington State Department of Fish and Wildlife, 2008).

Fish in the Coastal-Puget Sound population of Bull Trout are anadromous, as they spawn in rivers and streams but rear their young in the ocean. Designated critical habitat for anadromous Bull Trout in Washington includes 655 nautical miles of streams and shoreline (Map 7) (U.S. Fish and Wildlife Service, 2015). The shoreline critical habitat stretches from north of La Push south to Grays Harbor (U.S. Fish and Wildlife Service, n.d.).

Green Sturgeon are believed to spend most of their lives in nearshore oceanic waters, bays, and estuaries. The southern distinct population (SDP) of Green Sturgeon spawns only in the Sacramento River in California, and is listed under the Endangered Species Act as threatened (Adams et al., 2007). Adult sturgeon from the SDP enter Willapa Bay in 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, amphipods, and even small fish (NOAA Fisheries, 2014a). Green Sturgeon ESA critical habitat is within much of the Study Area. It occurs along the entire coast, including Grays Harbor and Willapa Bay (Map 7) (NOAA Fisheries, 2014a).

Pacific Eulachon (aka "candlefish" or "smelt") are small anadromous fish that typically spend three to five years in salt water before returning to fresh water to spawn. While in the ocean, eulachon typically spend their time in nearshore waters and offshore in waters up to 1,000 feet(300 meters) deep. Eulachon populations have declined in the last two decades, partially due to changing ocean conditions. The fish was listed as threatened under the ESA in 2010 (NOAA Fisheries, 2015). The latest status review notes that the population has increased since its listing in 2010; higher estimates may also be a result of improved monitoring (Gustafson et al., 2016). Eulachon are also key prey for pinnipeds in the MSP Study Area including harbor seals, California sea lions, Steller sea lions, and Northern fur seals (National Marine Fisheries Service, 2016). The MSP Study Area is important habitat for eulachon, and eulachon ESA critical habitat is directly adjacent to the Study Area. Eulachon are an important cultural fishery for many tribes in Washington.

Table 2.1-2. Anadromous fish species found (at some point in their adult life stage) within the MSP Study Area. Source: Washington State Department of Fish and Wildlife, 2017b.

Common Name	Scientific Name	Federal Status	State Status
Bull trout	*Salvelinus confluentus*	Threatened	State candidate
Chinook Salmon	*Oncorhynchus tshawytscha*	See Table 2.1-3 below	
Chum Salmon	*Oncorhynchus keta*	See Table 2.1-3 below	
Coho Salmon	*Oncorhynchus kisutch*	See Table 2.1-3 below	
Pink Salmon	*Oncorhynchus gorbuscha*	None	None
Sockeye Salmon	*Oncorhynchus nerka*	See Table 2.1-3 below	
Steelhead	*Oncorhynchus mykiss*	See Table 2.1-3 below	
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

Table 2.1-3. Listed Salmon ESUs that may be found in the MSP Study Area. Source: Washington State Department of Fish and Wildlife, 2017b.

Common Name	ESU	Federal Status	State Status
Chinook Salmon	Puget Sound	Threatened	State candidate
	Upper Columbia River	Threatened	State candidate
	Snake River spring/summer	Threatened	State candidate
	Snake River fall-run	Threatened	State candidate
	Upper Willamette River	Threatened	State candidate
	Lower Columbia River	Threatened	State candidate
Chum Salmon	Columbia River	Threatened	State candidate
	Hood Canal summer-run	Threatened	State candidate
Coho Salmon	Lower Columbia River	Threatened	None
	Oregon coast	Threatened	N/A
Sockeye Salmon	Snake River	Endangered	State candidate
	Lake Ozette	Threatened	State candidate
Steelhead	Puget Sound	Threatened	None
	Upper Columbia River	Threatened	State candidate
	Snake River Basin	Threatened	State candidate
	Middle Columbia River	Threatened	State candidate
	Upper Willamette River	Threatened	State candidate
	Lower Columbia River	Threatened	State candidate

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). Their diets vary and include krill, invertebrates, forage fish, salmon, other fish, 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 mammal in nearshore waters, and the Dall's porpoise the most commonly sighted marine mammal in 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

Orcas (aka killer whales) are also found in the MSP Study Area.[18] 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 bottomfish. 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 for the summer months, when the most monitoring has occurred. During this time, the northern resident population has a core range in inshore British Columbia. The southern resident 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). The NOAA Northwest Fisheries Science Center, Cascadia Research Collective, and the U.S. Navy use satellite tags on the resident orcas to learn more about their winter migrations and the extent of their range. Satellite tagging data from 2015 shows that the resident orcas spend time feeding outside the Willapa Bay and Grays Harbor estuaries and at the mouth of the Columbia River (NOAA Fisheries, n.d.-b).

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 2.1-4) (Lance et al., 2011).

Seals and sea lions

Harbor seals, elephant seals, California sea lions, and Steller sea lions aggregate and haul out on the rocky islands, coastal areas, and estuaries the MSP Study Area (Map 10) (S. J. Jeffries, Gearin, Huber, Saul, & Pruett, 2000; Lance et al., 2011). 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). NOAA's National Centers for Coastal Ocean Science (NCCOS) developed relative density models for the to inform the likely distributions of these animals in the MSP Study Area (excluding their use of the estuaries). Please see Chapter 3 for a more detailed description of the modeling process and results.

[18] 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 nearshore waters from Alaska to central California (Lance, Calambokidis, Baird, & Steiger, 2011).

Table 2.1-4. Marine mammals within the MSP Study Area on the federal or state Species of Concern lists. Source: Washington State Department of Fish and Wildlife, 2017c.

Common name	Scientific 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[19]	Endangered[20]
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

Sea otters

A population of sea otters also occurs in the Study Area. They typically inhabit rocky habitats and kelp forests, but also are found in lower densities in soft-sediment areas along the Olympic Peninsula coast from Destruction Island northward to Tatoosh Island (Map 10) (Andrews et al., 2013). Extirpated by fur trade hunters in 1911, sea otters were reintroduced to the outer coast in 1969 and 1970 (Lance et al., 2011). The sea otter population has continued to grow since reintroduction, with an annual growth rate of 7.6% between 1991 and 2012 (Washington State Department of Fish and Wildlife, 2013). The population in 2015 consisted of approximately 1,394 animals (S. Jeffries, Lynch, & Thomas, 2016). Sea otters are listed as endangered by the State of Washington (Washington State Department of Fish and Wildlife, 2017c).

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). Other sea otter prey includes abalone, mussels, crabs, snails, and chitons (Andrews et al., 2013).

Marine mammals with special protection

Ten marine mammal species listed under the federal ESA or Washington Species of Concern list occur within the MSP Study Area (Table 2.1-4). Stressors for marine mammals include collisions with boats and other boat interactions (e.g. noise), entanglement in fishing gear

[19] This listing is for the Southern Resident Orca population, the other three populations (northern, offshore, and transient) are not listed under the ESA.
[20] The State of Washington lists all Killer Whales in the state as Endangered.

and marine debris, contaminants, oil spills, alterations in habitat and prey, HABs, and oceanographic conditions (Andrews et al., 2013; Olympic Coast National Marine Sanctuary, 2011). All marine mammals, whether listed under the ESA or as a state Species of Concern, are currently protected by the Marine Mammal Protection Act (16.U.S.C. §§1631 et seq).[21]

Marine mammal mapping

The National Centers for Coastal Ocean Science (NCCOS) developed relative density models for four species of cetaceans and two species of pinnipeds to inform the likely distributions of these animals for the MSP. Species were chosen by Ecology and WDFW because they are species of management concern or are representative of specific ecological roles in the environment (C. Menza et al., 2016). The maps were created by using models that link at-sea mammal observations with environmental data. Cetacean maps were produced for Dall's porpoise (*Phocoenoides dalli*), harbor porpoise (*Phocoena phocoena*), gray whale (*Eschrichtius robustus*), 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. NCCOS also produced models and maps for harbor seal (*Phoca vitulina*) and Steller sea lion (*Eumetopias jubatus*). More details on the NCCOS modeling effort and available maps are in Chapter 3: Spatial Analyses.

The interagency team worked to identify ecologically important areas (EIAs). EIAs are defined as areas where available data shows that animals, especially those of interest in fisheries and wildlife management, use the MSP Study Area the most. More information about the EIA analysis process and additional maps are available in Chapter 3: Spatial Analyses. WDFW produced an EIA hotspot map for all marine mammals included in the analysis (Map 8) and one specifically for humpback whales (Map 9).

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 the offshore waters of the MSP Study Area, 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.

The interagency team developed EIA maps for some bird species. Additional information and maps can be found in Chapter 3: Spatial Analyses.

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

Marshbirds

The term marshbird broadly encompasses birds that feed, nest, or otherwise utilize tidal or freshwater marshes, including herons, egrets, rails, and passerines. They do not swim, but rather forage on sandy beaches, in marshes, and in 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 of these birds occur during the winter, and 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 the Black Brant (*Branta bernicla*), Greater Scaup (*Aythya marila*), Green-winged teal (*Anas crecca*), tundra swan (*Cygnus columbianus*), bufflehead (*Bucephala albeola*), Canada Goose (*Branta canadensis),* 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 migratory stopovers to rest, feed, and replenish the 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*).

There are also a few 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 in areas adjacent to and within the MSP Study Area, along the rocky coast and on 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

Seabirds include species of albatrosses, petrels, shearwaters, and alcids. Seabirds found within the MSP Study Area include murres, puffins, albatrosses, fulmars, shearwaters, gulls, murrelets, cormorants, terns, and others. Seabird use of the area varies seasonally and is influenced by physical and biological processes. Some species travel vast distances across the globe to forage in the waters of the MSP Study Area 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 fish and invertebrates, including zooplankton, crabs, and crustaceans. 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 and poor at-sea foraging conditions are some of the primary pressures experienced by these birds. Marbled Murrelets are monitored annually in Washington (U.S. Fish and Wildlife Service, 1997; 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 and life history characteristics, 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 to inform the MSP, using environmental variables and survey data. Species were chosen to represent different habitat uses ranging 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*) (Charles Menza, Battista, & Dorfman, 2013). See Chapter 3: Spatial Analyses for more information and maps.

Map 12 shows the results of the Ecologically Important Areas hotspot analysis for seabirds.

Raptors

A few species of raptors forage in areas 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 2.1-5). 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, in Grays Harbor at Damon Point and

Johns River Island, and on the islands of the lower Columbia River (See Chapter 3: Spatial Analyses for the EIA map) (Washington State Department of Fish and Wildlife, 2013). Common reasons for bird population declines include oceanographic factors that affect their prey (e.g. El Niño), habitat degradation, pollution and oil spills, and predation (Kaplan et al., 2010; Olympic Coast National Marine Sanctuary, 2011). Birds are also susceptible to illness and death from consuming prey affected by HABs (NOAA, 2015).

National wildlife refuges, the Olympic Coast National Marine Sanctuary, WDFW, and DNR implement management measures to help protect and recover populations of listed species in Washington. Bald Eagles are also protected under the Bald and Golden Eagle Protection Act (16 U.S.C. 668) which prohibits anyone from "taking" Bald Eagles including their parts, nests, or eggs, or disturbing the birds.

Table 2.1-5. 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, 2017b.

Common Name	Scientific Name	Federal Status	State Status
Bald Eagle	*Haliaeetus leucocephalus*	Species of Concern	State Sensitive
Brandt'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 Endangered Species Act and on the Washington State Species of Concern list (Table 2.1-6). These sea turtles feed in and migrate through the waters of the Study Area. However, no nesting sites occur within

Washington State, as the turtles 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 the waters of the MSP Study Area 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 for turtles 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. Therefore, the risk of entanglement is now quite low (Washington State Department of Fish and Wildlife, 2013). NOAA's Critical Habitat Designation identifies an area of nearshore waters from Cape Flattery, Washington to Cape Blanco, Oregon that includes important habitat for foraging of prey that is important to leatherbacks.

In this habitat of high conservation value, tidal, wind, wave energy, and liquid natural gas projects were identified as having the potential to affect prey abundance and prey contamination levels (NMFS Southwest Fisheries Science Center, 2012). Sightings of loggerhead and green sea turtles are rarely recorded off the Washington coast. Only four strandings of green sea turtles were recorded between 2002 and 2012. No strandings of loggerheads were recorded in that period (Washington State Department of Fish and Wildlife, 2013).

Table 2.1-6. Sea turtles within the MSP Study Area and their federal and state species of concern status. Source: Washington State Department of Fish and Wildlife, 2017b.

Common Name	Scientific 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 anthropogenic stressors, or stressors from human activities. 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 discharges, fishing pressures including habitat modifications related to bottom gear, shoreline development, human disturbance and trampling, ocean noise, and vessel strikes.[22] While this is not meant to be an exhaustive discussion of various human stressors that affect ocean ecology, these topics are presented to acknowledge the major identified impacts that Washington's ocean environment currently faces.

[22] Climate change is discussed in Section 2.11 Climate Change.

Invasive Species

Invasive species are non-native organisms that harm or pose a risk of harming the state's environmental, economic, or human resources.[23] 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 in a variety of ways, including ballast water discharge, the use of organisms for packing material, fouling on aquaculture shipments, the aquarium trade (with subsequent release into the environment), recreational boating, and floating debris (e.g. biofouling on debris arriving from the 2011 Japanese tsunami) (Andrews et al., 2015, 2013; Office of National Marine Sanctuaries, 2008).

Invasive species can have a profound impact on the habitat, trophic interactions, and ecology of an area. This can also lead to significant social and economic burdens on industries such as fisheries and aquaculture, and can particularly impact the recovery of species such as salmon (Office of National Marine Sanctuaries, 2008). Statewide, there are 94 recorded marine invasive species, 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 about its impacts to native species or other algae in Washington (Skewgar & Pearson, 2011).

The prevention and control of invasive species is a complex task and depends upon how a species is introduced or spread, as well as the effective treatments available for that 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 prohibitions of 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 case of established invasive populations, Washington may take direct action to control and prevent further spread of species that are significant threats to native habitat and/or natural resource industries. The management approaches used in these situations, ranging from physical removal to application of pesticide treatments, depend 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 accomplished using physical removal (Washington State Department of Fish and Wildlife, 2015c). However, 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).

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

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

related to the prevention and control of invasive species.[24] These programs focus on various aspects of invasive species outreach, education, reporting, prevention, enforcement, and treatment.

Invasive species will continue to be a stressor in the future with a significant risk of impact to 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 introduce invasive species.

It should be noted that some introduced species have become important for commercial and recreational harvest in the MSP Study Area. Pacific Oysters and Manila Clams are both non-native species that were introduced to the area. Pacific Oysters were introduced to the MSP Study Area as spat from Japan beginning in 1928. They are now the focus of economically important aquaculture operations that contribute significantly to the coastal and statewide economy (for more information see Section 2.5 Aquaculture) (Industrial Economics Inc., 2014).

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.

The West Coast Offshore Vessel Traffic Risk Management Project developed recommendations that vessels 300 gross tons or larger that are transiting coastwise anywhere between Cook Inlet and San Diego should voluntarily stay a minimum distance of 25 nm offshore (West Coast Offshore Vessel Traffic Risk Management Project Workgroup, 2002). As a result, larger vessels including oil 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 the 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. This includes the 1972 spill of 2,300,000 gallons of heavy fuel oil off Clallam County and the Makah Reservation by the troop transport vessel *USS General M.C. Meigs* under tow. Other notable spills are the 1988 *Nestucca* barge spill off Grays Harbor (231,000 gallons of heavy fuel oil) and the 1991 *Tenyo Maru* fishing vessel spill off Cape Flattery and the Makah Reservation (100,000 gallons of diesel and heavy fuel oil released in initial incident, with the vessel containing over 400,000 gallons when it sank) (Washington State Department of Ecology, 2007). Smaller spills occur more

[24] 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, and the Washington Department of Ecology's Aquatic Weeds Program.

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 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 for and response to spills. OCNMS initially promoted and currently monitors compliance with the Area to be Avoided.[25] The ATBA is a voluntary measure that routes large vessels offshore and decreases the 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 a key concern for federal agencies, state agencies, local governments and communities, tribes, and industry. The Region 10 Regional Response Team and Northwest Area Committee focus on oil spill prevention, planning, and response. Participating agencies include the U.S. Coast Guard, EPA, and Ecology. More information on proposed oil projects and oil spill response is provided in Section 2.7: Marine Transportation, Navigation, and Infrastructure.

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 harmful 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, costs associated with cleanup, degradation of beaches and habitat, vessel damage, and navigation hazards. Marine debris can also introduce non-native species, which can have both ecological and economic impacts on an area (NOAA Office of Response and Restoration, 2017).

Marine debris is present along the entire coast of the MSP Study Area and comes from a variety of sources. Human trash from direct beach recreation activities and 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 occurred in 2011. Tsunami debris has included a variety of objects such as construction materials, boats, a large dock, and some hazardous materials like propane tanks. Non-native species have often been found attached to this debris, requiring removal. Tsunami debris has been intermittent and widely scattered, sometimes in significant quantities, but reports have become rare in recent years. It is often difficult to tell if debris was lost during the tsunami because marine debris is a daily problem. Efforts to safely remove tsunami debris have been coordinated by NOAA, the State, and others. NOAA continues to work with other federal, state,

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[25] The Area to be Avoided is a boundary indicating 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 25nm 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)(Olympic Coast National Marine Sanctuary, 2013).

local, and tribal partners to monitor and remove tsunami debris (Barnea, 2015; NOAA Office of Response and Restoration, 2017).

Several marine debris volunteer cleanup events occur yearly on beaches in the Study Area. Currently, most of these cleanups are coordinated by the Washington CoastSavers with many nonprofit, business, and government organizations participating. While CoastSavers has been coordinating cleanup events since 2007, community groups have held cleanup events on the Washington coast as early as 1971 (Washington CoastSavers, 2015). Other organizations that contribute considerably to beach cleanups include Washington State Parks, the Grassroots Garbage Gang, and Surfrider Foundation chapters. Significant annual marine debris collection events include the Washington Coast Cleanup held in April around Earth Day, the International Coastal 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 that 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 (abandoned or lost) fishing gear from Washington's Pacific coast. All fixed gear fisheries (hagfish, shellfish, and groundfish) are required to have biodegradable escapes as part of gear design (WAC 220-360-220, WAC 220-340-060, WAC 220-300-050, and WAC 220-355-070). Other types of derelict gear can continue to catch fish, crabs, and other 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. Removal benefits the crab, the fishermen, and the environment (M. 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 are effectively managed to prevent entry of debris into the environment.

Vessel Discharges

All types of vessels generate wastewater. The type and amount of wastewater generated depends on the vessel and its passenger load, size, function, and condition. Examples of wastewater include sewage, graywater (e.g., water from showers or dishwashing), bilgewater (a mixture of engine water, cleaning agents, and many other sources), and ballast water (water used for stability). Sewage can be directed to a marine sanitation device to either treat the material prior to discharge, or to hold it until it can be pumped to a land-based facility.

There are concerns surrounding the water quality impacts vessel discharges could have on 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. As one example, 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).[26] The VGP contains restrictions on the discharge to OCNMS waters, and to the waters of Flattery Rocks and Willapa National Wildlife Refuge in the MSP Study Area, as well as several other waters within the state.[27]

The amount of wastewater discharged into the MSP Study Area is unknown, however cruise ships are one factor with the potential to contribute significant quantities. OCNMS regulations implemented in 2011 now prohibit all cruise ship wastewater discharges within sanctuary waters (15 CFR §922.152). In state waters, Ecology regulates waste discharge and has developed a Memorandum of Understanding (MOU) with the Cruise Lines International Association North West & Canada and the Port of Seattle to outline requirements. The MOU prohibits discharges of sewage and graywater from all cruise ships except when discharges are treated with advanced wastewater treatment systems. In addition, no discharges are allowed within 0.5 mi of shellfish beds, and sampling and monitoring of wastewater discharges is required (Washington State Department of Ecology, 2016b).

In addition to cruise ships, all vessels including recreational, fishing, commercial, and other passenger vessels generate wastewater. Vessel discharges must meet state water quality standards. However, many onboard treatment systems do not meet these standards, so vessels are guided to use onshore pumpout facilities or withhold discharges until outside of state waters (Olympic Coast National Marine Sanctuary, 2011). Additionally, Ecology is in the process of developing a no discharge zone in Puget Sound. The EPA has found that there are adequate pumpout facilities in Puget Sound to do so, and Ecology will move forward with rulemaking (Washington State Department of Ecology, 2017). The EPA is currently in the process of developing an NPDES permit for discharges from fish processing vessels off the coasts of Washington and Oregon. The original draft permit was released for public comment at the end of 2015 and a revised draft permit is expected in 2017. The draft permit establishes standards and exclusions for discharge of fish processing effluent into federal waters off the coast. The draft permit does not authorize the discharge of pollutants into inland or state waters (U.S. Environmental Protection Agency, 2015).

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, Washington State, and the coastal treaty tribes.[28] The MSP Study Area has a long history of fishing activity, with some periods of unsustainable and habitat-damaging practices.

[26] 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
[27] 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
[28] For more information on fisheries and management, please see Section 2.4: State and Tribal Fisheries.

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). Researchers have found that trawl activity in soft sediments has minor impacts on the seafloor including leaving scour marks, but has minimal impacts on the topographic structure of the seafloor or the densities of invertebrates (Lindholm et al., 2013).

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).

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 for non-tribal commercial fishermen are expected to aid in the recovery of depleted groundfish stocks as well as to allow 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 by causing changes to sediment supply or loss of beach habitat. As coastal populations continue to grow, these changes represent a potential increasing stressor to the natural system. The northern half of the MSP Study Area coast (Clallam and Jefferson Counties) is largely undeveloped. New coastal development in this area will likely remain limited in the foreseeable future, partially due to the presence of Olympic National Park. 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 the 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 the 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 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 food detection. Noise within the ocean can be natural, such as that generated from animals, 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, military activities, 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 animals' communication ranges and their ability to sense their environment (Hatch & Broughton, 2015).

Researchers have studied the impacts of ocean noise on Southern Resident killer whales and found that vessel noise affects echolocation abilities of foraging whales. Studies also found that killer whales spend a greater proportion of time traveling and less time foraging in the presence of vessels (NOAA Fisheries, 2014c). 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 focusing 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 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, especially large whales, is a known stressor globally, particularly in areas where high amounts of ship traffic and large whale populations intersect (Douglas et al., 2008; Redfern et al., 2013). Whales are vulnerable to strikes from all vessel types, and vessel strikes can lead to animal injury and death. Large vessel crews may not even notice when a strike has occurred. Additionally, 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 number of documented incidents (Douglas et al., 2008; National Marine Sanctuaries, 2015; Redfern et al., 2013). In Washington, blue whales, fin whales, and gray whales have been struck and killed by ships (Lance et al., 2011).

The West Coast Marine Mammal Stranding Network collects data on stranded marine mammals in Washington, Oregon, and California. Participants in the stranding network are authorized by NOAA to respond to stranded marine mammals and to examine dead marine mammals. Information gathered from strandings contributes to research and public education and to the implementation of NOAA Fisheries mandates under the Marine Mammal Protection Act and the Endangered Species Act (NOAA Fisheries, n.d.-c).

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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 the MSP Study Area. Washington's coastal areas are rich with cultural resources. These resources include archaeological sites providing prehistoric records of native peoples' marine-oriented uses, and traditional cultural properties associated with the cultural practices, traditions, beliefs, lifeways, arts, crafts, or social institutions of living communities. 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 its 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 is located within the Ozette Reservation and establishes human presence in the area for at least the last 6,000 years (Olympic Coast National Marine Sanctuary, 2011). It is likely that humans may have been present along the West Coast as early as before 14,500 BP (Before Present) (ICF International, Southeastern Archeological Research, & Davis Geoarchaeological Research, 2013).

The native peoples of the Washington coast relied heavily on ocean and coastal resources, as they continue to do today. Archeological sites, traditional oral histories, and ethnographies provide records of the types of marine-oriented uses participated in by the coastal tribes during prehistoric times and in the years up to the signing of the treaties. Marine resources not only served subsistence purposes, but also played an integral role in native peoples' cultures, ceremonies, and economies.

While specific uses varied for each tribe, native peoples harvested many different species from the ocean, estuaries, and bodies of fresh water. These living resources include but are not limited to: salmon, steelhead, halibut, cod, sea bass, sole, rockfish, and crabs. They also harvested shellfish and hunted seals, sea lions, sea otters, and whales. Some communities developed specialized gear for fishing, sealing, and whaling. Examples include 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 at various types of coastal archaeological sites and in 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 include the Ozette Indian Village Archaeological Site, Tatoosh Island, and the Wedding Rock Petroglyphs (Olympic Coast National Marine Sanctuary, 2011). Enormous middens have also been discovered in La Push, providing a connection between native peoples and their 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 the Washington State Department of Archaeology and Historic Preservation (DAHP).

Due to changes in sea level since prehistoric times, it is very possible that prehistoric Native American archeological sites exist that are now submerged beneath the ocean. Sea level was at its lowest at about 19,000 BP, when the shoreline was located up to about 30 miles offshore from the present-day shoreline in some locations. Since then sea level has risen at varying rates, pushing possible prehistoric occupants farther and farther inland (ICF International et al., 2013). The Bureau of Ocean Energy Management (BOEM) modeled paleoshorelines from 19,000 BP to 1,000 BP in federal waters to illustrate how shoreline locations have 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 rich maritime history of Washington's Pacific coast that began with the coastal tribes expanded when Europeans first encountered the coast as early as 1579. 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 and profitable industries. Maritime trade and the foggy, dangerous conditions of the coast necessitated the construction of lighthouses. The Cape Disappointment lighthouse 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 to transport 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. Many of these industries 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 that are 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. Historically, fog, waves, storms, strong currents, sand bars, and a rugged coastline made 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. These ships ranged from clippers and steam freighters to fishing boats and barges. Several wrecks are famous in local lore (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 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 of spiritual power or healing, places 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.

Some historical resources and traditional cultural properties may also be sensitive to various levels of visual disturbance from new ocean uses, such as offshore wind. The state analyzed how far offshore objects of different heights would be visible from shore (Map 15). This coarse assessment is useful in understanding what types of structures may be visible from the coast, but specific assessments for individual projects will be needed to evaluate the full potential visual impact from any 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) (http://marineprotectedareas.noaa.gov/toolkit/cultural-landscape-approach.html). The CLA provides a means for developing new levels of information about marine areas and their resources by integrating 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 their economy and cultural character. 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, the Makah Tribe, Quileute Tribe, Hoh Tribe, Quinault Indian Nation, and Shoalwater Bay Tribe (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 the resulting inundation. Continued participation in marine resource-based industries, a healthy marine ecosystem, and a future with a sustainable local economy are among the commonly shared visions of many coastal residents (Butler et al., 2013; Kliem, 2013).

Funding was provided through the marine spatial planning process to gather social and economic information for coastal counties and tribes adjacent to the MSP Study Area. This section briefly summarizes the extensive information provided by 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. Additional economic analyses specific to individual current uses in the MSP Study Area are referenced in the relevant sections of Chapter 2.

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[1] Economic information specific to each marine industry is provided under the relevant sections within Chapter 2 of the Marine Spatial Plan.

County Profiles

Primary socioeconomic measures for the four coastal counties are presented in Table 2.3-3. The four coastal counties are rural along the Pacific coast. In Clallam and Jefferson Counties, the majority of centers are in areas not adjacent to the Pacific Coast.[2] For each county, the median household income is below the state average and the unemployment rate is higher than the state average. The information presented below includes tribal and non-tribal data, and it should be noted that information collected and reported by the state of Washington categorizes all employment by tribe-owned establishments as "government."

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). Grays Harbor County has the lowest proportion at 13%, yet it still represents a significant element of total employment (Table 2.3-4). 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 2.3-3. Socioeconomic parameters for the four coastal counties[3] and Washington State (tribal and non-tribal data).

	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%
Percent 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 2.3-4. Ocean economy[8] of individual counties, the Pacific Coastal counties combined, and Washington State. (Tribal and non-tribal data)

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 Pacific shoreline adjacent to the MSP Study Area is

[8] Ocean-related industries included in NOAA's Economics: National Ocean Watch (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)

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 levels of 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 the 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 of Port Angeles is not located within MSP Study Area (Taylor et al., 2015).

A zip code-based analysis revealed that Pacific Coast-based businesses accounted for only 4% of Clallam County's ocean-dependent activity. 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 comprises 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. 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 Pacific shoreline adjacent to the MSP Study Area almost entirely within 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 levels of 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 account for 14% of Jefferson County's ocean-dependent activity, while 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. The 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 levels of 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).

Grays Harbor County is part of the Columbia Pacific Resource Conservation and Economic Development District. The District identified four natural resource-related industrial clusters considered integral to the Columbia-Pacific region's 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 by the Columbia River to the south. Pacific County includes the North Beach Peninsula (aka 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, or about 4% of the county. More than 70% of the county is forested, or close to 420,000 acres (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 levels of 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%). This sector has a location quotient of more than 2.7 times more concentration as compared to the rest of the state, and more than 9.4 times more concentration in the 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 agriculture, 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, the Port of Peninsula, the Port of Ilwaco, and the Port of Chinook.[11]

[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.

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, including resorts and marinas.

In addition, commercial, ceremonial, and subsistence fishing activities occur off-reservation in usual and accustomed fishing grounds (U&As) for treaty 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. The socioeconomic profiles below include information about the economic value of marine resource-based industries such as fishing and tourism to the tribes. However, it is commonly recognized that while economic analysis is a useful tool, it does not encapsulate the cultural and spiritual values that marine resources represent to tribal communities.

Makah Tribe

The Makah Reservation is located on the northwestern most tip of the Olympic Peninsula and covers about 47 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, Neah Bay is the primary community on the Makah Reservation and is located 60 miles north of Forks and 75 miles northwest of 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 a 30% grade and only 6% of the roads are paved (Taylor et al., 2015).

In 2010, 1,414 individuals were living on the reservation. 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, healthcare 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).

[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.

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 include expanding the four tourist-oriented enterprises in the short term, and possibly developing 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 to the mainland at extreme low tides. The reservation is located on the Olympic Peninsula and is roughly bounded by the Quillayute River, the Pacific Ocean, and Olympic National Park (Map 2). Much of the reservation is surrounded 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 2016 estimated tribal enrollment was 806 members. Industry clusters with the highest levels of employment from 2009-2013 were educational services, healthcare, and social assistance (46.1%); public administration (28.9%); and agriculture, forestry, fishing and hunting, and mining (13.8%). The median earnings for workers on the Quileute Reservation were $24,205 for 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, 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 the acquisition of 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). Additionally, the reservation acreage was doubled after 2012 federal legislation (PL 112-97) designed to enable moving much of the village to higher ground to minimize risk to the community from tsunamis. The Tribe has a major multidepartmental effort underway called Move to Higher Ground, and has completed a hazard mitigation study.

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). However, the changing course of the Hoh River and the 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 for 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 focuses on the regeneration of tree species for cultural use. Plans for the future include using the lands added 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, and is mostly forested. It 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 to the east, and Moclips to the south. The rainforest climate brings 80 inches of precipitation to 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, industry clusters providing the highest proportion of employment included educational services, healthcare, and social assistance (33.2%); public administration (28%); and arts, entertainment, recreation, accommodation and food services (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 employee positions. 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 was created by executive order in 1866 (Shoalwater Bay Tribe, 2017). 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 coastal 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, recreation, accommodation, and food services (33.3%); educational services, healthcare and social assistance (26.4%); and public administration (18.1%). The U.S. Census Bureau estimates that over 40% of workers on the reservation are government employees, and about 43% of jobs are 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 the 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 economic report that estimated economic contributions of commercial and recreational fisheries, aquaculture, and recreation and tourism to local and state economies. Cascade Economics, Inc. 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. They 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 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 their respective sections 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.

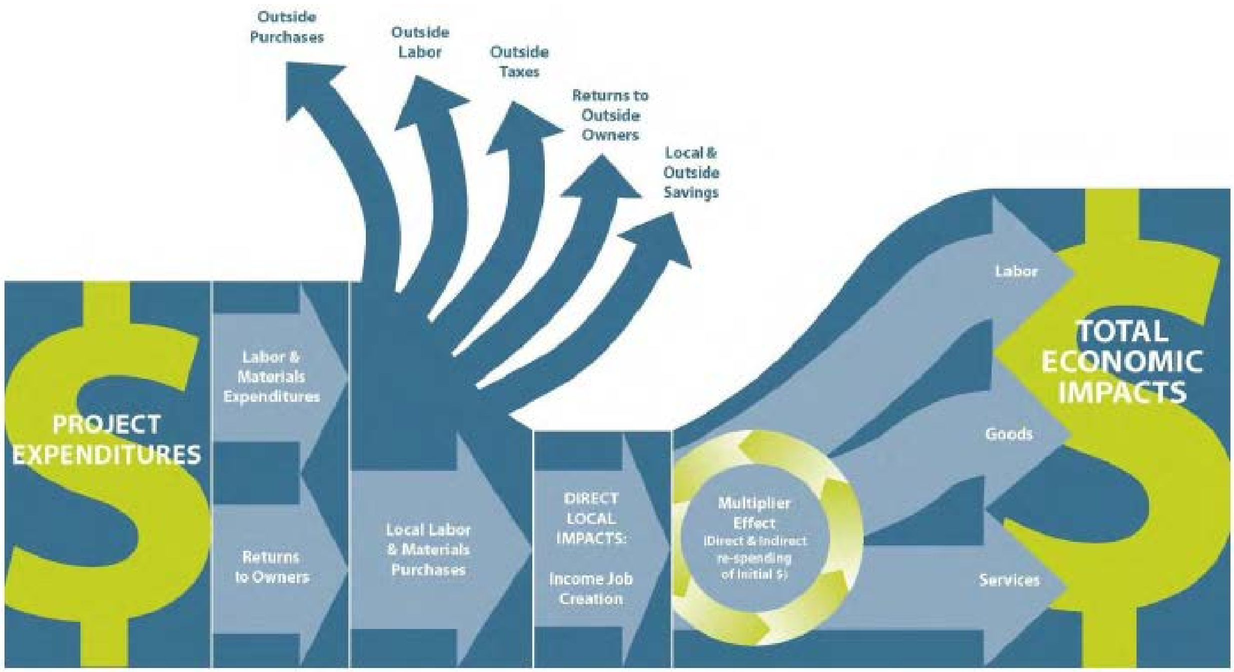

Figure 2.3-1: Illustration of regional economic impacts, leakage, and multiplier effects. Source: Northern Economics, Inc., 2013.

Coastal Hazards and Community Vulnerability

Washington coastal communities are exposed to various 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 outside the scope of the MSP, a general description of

[13] 2014 commercial landing 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.

Washington 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). 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 extreme high tides, also known as king 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 (accumulation of sediment) 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 cause 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. However, 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 2.3-5. These numbers do not account for the thousands of visitors who travel to coastal areas every day (Washington Emergency Management Division, 2013).

Table 2.3-5. 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 other public facilities outside of the tsunami hazard zone (Taylor et al., 2015). [16,17]

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

[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.

[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).

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 are working to understand, prepare for, respond to, and mitigate against various natural hazards to reduce risk and increase community resilience. This work is being done in coordination with EMD, the Federal Emergency Management Agency (FEMA), Ecology's Coastal Program, Washington Sea Grant, and other local, state, and federal agencies. One example is the Coastal Hazards Resilience Network, which brings together federal and state government agencies, tribes, 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 the 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://media.wix.com/ugd/e2eea5_7a4796fc90c3f86ff0ae22e675bd6b55.pdf

- *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 provided important context for social and economic interests and concerns during the marine spatial planning process. The section below briefly 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 was 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. The desire to protect existing marine resource industries, such as fishing and

[18] More information available at www.wacoastalnetwork.com.

aquaculture, was shared by a wide range of participating stakeholders (Butler et al., 2013; Kliem, 2013). This view was further highlighted through the development of goals by stakeholders and government officials to guide the MSP. The goals adopted include to "protect and preserve existing sustainable uses to ensure economic vibrancy and resource access for coastal communities."

Other themes included the importance of a healthy marine ecosystem, and access to natural resources for jobs and the enjoyment of 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 a 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 will share similar challenges and opportunities in 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 expansions 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 State and Tribal Fisheries

In the marine planning law for Washington's marine waters, fishing is recognized as a longstanding and important use of the MSP Study Area. Among the policies the law establishes for the state to follow when conducting marine spatial planning, one requires state planners to "recognize 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)). The law also mandates that "any provision of the marine management plan that does not have as its primary purpose the management of commercial or recreational fishing but that has an impact on this fishing must minimize the negative impacts on the fishing" (RCW 43.372.040(8)).

This section recognizes fishing's importance by describing the state and tribal fisheries that occur within the MSP Study Area and highlighting some of the key benefits that they contribute to coastal communities and to the state. The MSP's framework for minimizing negative impacts to fishing is described in Chapter 4: MSP Management Framework.

Note on Sources and Terminology

The information presented in this section is summarized primarily from two reports that were produced specifically for this planning effort by Industrial Economics (2014) and Taylor et al. (2015). Readers are encouraged to consult the two reports for further detail. In addition, the basic fisheries statistics on which both reports rely are collected and maintained by the Washington Department of Fish and Wildlife (WDFW) and the coastal treaty tribes. These statistics are publicly available upon request, subject to certain restrictions in place to protect confidentiality of individual fishery participants.

- Industrial Economics Inc. (2014). Marine sector analysis report: Non-tribal fishing (Sector Analysis Report; Washington Department of Natural Resources Contract No. SC 14-327). Prepared for the Washington Coastal Marine Advisory Council. Retrieved from http://msp.wa.gov/wp-content/uploads/2014/03/FishingSectorAnalysis.pdf.

- Taylor, M., Baker, J. R., Waters, E., Wegge, T. C., & Wellman, K. (2015). Economic analysis to support marine spatial planning in Washington. Prepared for the Washington Coastal Marine Advisory Council. Retrieved from http://www.msp.wa.gov/wp-content/uploads/2014/02/WMSP_2015_small.pdf.

In addition, the term "commercial" in this section should not be read to include treaty tribal fisheries. Tribal fisheries are often described separately because they are conducted under special authorities held by tribal governments. Many tribal fisheries, however, are comparable to non-tribal commercial fisheries in the areas they fish, the fishing methods they use, and the markets into which they sell their catch. On a similar note, tribal members also harvest fish and shellfish non-commercially, for ceremonial and subsistence purposes, yet they would not refer to these fishing activities as "recreational" fishing. The specific fishing activities of the four coastal treaty tribes are described in more detail 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 and early European settlers began commercial fishing when they arrived in the region in the mid-1800s. Today, tribal and coastal communities remain highly engaged, reliant, and dependent on commercial, recreational, and tribal fisheries.

Recent studies have evaluated the engagement, reliance, and dependence of Washington's communities on fishing. Engagement is an absolute measure of fishing activity that can be measured by metrics like permits or pounds and values of landings. Reliance indices are relative measures such as permits per capita and value of landing per capita. Communities with high levels of both engagement and reliance on fishing are considered to be highly dependent on fishing (Jepson & Colburn, 2013).

A NOAA study identified a number of communities located adjacent to the MSP Study Area as being some of the most highly fishing dependent incorporated communities[1] on the West Coast (Table 2.4-6). This classification is based on both fisheries and social variables. The methodology in the 2017 study relies on social data available via the census that is only available for a census designated place. Therefore, unincorporated communities, such as La Push[2] and Nahcotta, were not included in the 2017 study. However, these communities, among others, are recognized as 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).

Table 2.4-6. Washington incorporated coastal communities adjacent to the MSP Study Area with high commercial fishing dependence. Source: Norman, NOAA Northwest Fisheries Science Center

Bay Center, Pacific County
Chinook, Pacific County
Ilwaco, Pacific County
Neah Bay,[3] Makah Indian Reservation, Clallam County
Taholah, Quinault Indian Reservation, Grays Harbor County
Tokeland, Pacific County
Westport, Grays Harbor County

[1] Fishing dependence was a combination of reliance and engagement indices for commercial and recreational fisheries. For details on methods, please see work by NOAA Northwest Fisheries Science Center at: https://www.nwfsc.noaa.gov/research/divisions/cb/ecosystem/humandim/analyses.cfm.
[2] Identified with South Bend, Tokeland, Bay Center, and La Push as communities with high fishing dependence and engagement in a 2007 NOAA study (Norman et al, 2007).
[3] Neah Bay is located outside, but adjacent to, the MSP Study Area.

The coastal communities adjacent to the MSP Study Area and their fishing activities are the primary focus of this section. However, the fishery resources of the MSP Study Area support a broader set of communities that can reach the Study Area through ports located within Puget Sound and along the Columbia River. More distantly located ports such those in the Blaine-Bellingham area of Washington and the Astoria-Warrenton area of Oregon have been as engaged in the fisheries of the MSP Study Area as communities that are located alongside it, such as Westport and Ilwaco.

Conversely, the Plan also recognizes that fishing communities adjacent to the Study Area are engaged in and dependent on fishing grounds elsewhere, such as those in Puget Sound and off Oregon, California, and especially Alaska.[4] Revenue earned by commercial fishing and seafood businesses from fisheries, like the Bristol Bay Sockeye Salmon fishery, contribute to the viability of these businesses. The Albacore Tuna fishery offers another example. Much of the commercial and recreational catch in this fishery occurs beyond the 700 fathom boundary of the MSP Study Area, yet still supports the communities of the coastal counties.

Fisheries Management

Washington's marine planning law provides the state with the option of including, at the discretion of WDFW's director, a "fishery management element" in the MSP, described as "existing fisheries management plans and procedures and standards for consideration in adopting and revising fisheries management plans in cooperation with the appropriate federal agencies and tribal governments" (RCW 43.372.040(7)). At this time, the state does not propose incorporating any such fisheries management elements into the MSP. Existing fisheries management processes are described below.

Almost every species supporting fisheries in the MSP Study Area migrates across or straddles jurisdictional boundaries. Shared jurisdiction over fisheries resources is the norm rather than the exception, and management of these resources involves a complex mix of state, federal, regional, and international processes. In addition, as further discussed in Section 1.6: Pacific Coast Indian Tribes and Treaty Rights, Washington is unique compared to other states because of the presence of tribal governments with 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 in several state, regional, and international fisheries management processes as well as in fisheries research and monitoring activities. This section briefly outlines existing fisheries management forums. More details are given below in the descriptions of individual fisheries.

In Washington, the state's principal authority for managing fisheries is delegated to WDFW. The Washington Fish and Wildlife Commission, which consists of nine citizen members appointed by the governor, holds rule-making authority and is responsible for setting fish and wildlife policy for WDFW. The Commission was established to provide an open and deliberative process that promotes public involvement and confidence in management decisions. WDFW'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."

[4] In contrast, tribal members fishing under their tribe's treaty right are restricted to their tribe's Usual and Accustomed fishing grounds (U&As).

The Pacific Fishery Management Council (PFMC) is another open and deliberative process for managing fisheries. It was established by Congress to sustainably manage fisheries in federal waters off the coasts of Washington, Oregon, and California. PFMC's voting membership consists of six governmental representatives and eight private citizens. The governmental representatives include representatives from WDFW; 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 a Fishery Ecosystem Plan and four fishery management plans (FMPs): Salmon, Groundfish, Coastal Pelagic Species, and Highly Migratory Species.

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. Idaho joined in 1963 as did 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 a forum for coordination between states for state-managed fisheries. For example, under the PSFMC, the states of Washington, Oregon, and California have the Dungeness Crab Tri-State Agreement to consult on issues affecting the commercial Dungeness Crab fishery.

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, the Pacific Salmon Commission, and the Pacific Hake/Whiting Treaty. These bilateral management agreements monitor shared stocks, establish sustainable catch levels, and allocate them among the two nations. The halibut and salmon stocks covered by the agreements also involve the fisheries and interests of Alaska.

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. Albacore management processes incorporate 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 fisheries and fishery sectors are described and grouped differently within the Cascade Economics report (2015) than in this section of the MSP, Table 2.4-7 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 fourth column. The far right column of the table provides source data for each map with a more detailed description of source data and development of the maps provided below the table. Map 17 shows the combined commercial and recreational fishing intensity for the MSP Study Area.

Table 2.4-7. Fisheries sector groupings and available maps (continued on following page)

Sector	Fishery grouping	Fisheries described in Section 2.4	Economic report description	Fisheries use maps available	Map Data Sources
Commercial	Groundfish	• Fixed gear • Bottom trawl • Midwater rockfish trawl • Whiting (shoreside and at-sea)	• At-sea Pacific Whiting • Shore-based fisheries (Whiting trawl and non-Whiting trawl) • Non-trawl	• Sablefish, fixed gear (Map 18)	• Industry interviews
				• Groundfish, bottom trawl (Map 19)	• State trawl logbooks (2003-2014)
				• Pacific Whiting (Map 20)	• At-sea Hake observer program logbooks (2003-2014) • State trawl logbooks (2003-2014)
	Salmon	• Ocean troll • Gillnet	• Salmon troll • Salmon net	• Salmon troll (Map 21)	• Industry and fishery manager interviews
	Highly Migratory Species	• Albacore Tuna	• Albacore Tuna[5]	• Albacore Tuna (Map 22)	• Highly Migratory Species commercial logbooks (1995-2014) • Industry interviews
	Coastal Pelagic Species	• Pacific Sardine	• Coastal pelagic species	• Pacific Sardine (Map 23)	• State logbooks (2002-2014)
	Shellfish	• Dungeness Crab • Pink Shrimp • Spot Prawn • Razor Clam	• Dungeness Crab • Shrimp • Other species[6]	• Dungeness Crab (Map 24)	• Tri-state logbooks (2009/2010-2013/2014 seasons)
				• Pink Shrimp (Map 25)	• State logbooks (2011-2014)
	Pacific Halibut	• Pacific Halibut	• Other species[6]		
	Other	• Hagfish	• Other species[6]		

[5] Some tables report within a general Highly Migratory Species grouping, which is referenced as being comprised of mostly Albacore Tuna.
[6] Other species includes Spot Prawn, Pacific Halibut, and Hagfish.

Table 2.4-7 (continued). Fisheries sector groupings and available maps

	Fishery grouping	Fisheries described in Section 2.4	Economic report description	Fisheries use maps available	Map data sources
Recreational	Salmon	• Salmon	• Salmon • Steelhead	• Salmon (Map 26)	• Industry and fishery manager Interviews
	Groundfish	• Bottomfish	• Bottomfish	• Bottomfish and Lingcod (Map 27)	• Industry and fishery manager interviews
	Halibut	• Pacific Halibut	• Pacific Halibut	• Pacific Halibut (Map 28)	• Industry and fishery manager interviews
	Highly Migratory Species	• Albacore Tuna	• Albacore Tuna	• Albacore Tuna (Map 29)	• State Charter Logbooks (2006-2014) • Industry Interviews
	Shellfish	• Razor Clam • Dungeness Crab	• Razor Clam	• Razor Clam (Map 30)	• Known WDFW and tribal management areas • DOH

About Fisheries Maps and Data

The fisheries use maps used in the Plan were developed by WDFW to summarize available information on areas of high importance to fisheries, as required by RCW 43.372.040(6)(c). Identifying the footprint of each fishery was the primary goal. The areas within each footprint, which represent the area where fishing has occurred or has the potential to occur, should be considered to be of potential importance to fishing. The next step—identifying areas of high importance within each footprint—is a more difficult task given limitations in the available spatial information. WDFW used three general approaches to identify areas of relatively high, medium, and low use intensities:

1. *Fishery logbook data and percentile rankings*: Each hexagon was ranked based on the number of intersecting fishing sets or tows and scored using three bins:
   a. "High"- Top 25% of hexagons
   b. "Medium"- Middle 50% of hexagons
   c. "Low"- Bottom 25% of hexagons
2. *Logbook data with criteria-based intensity definitions*: Limited location and effort data is presented in logbooks for some fisheries. As a result, each hexagon was evaluated based on available effort data and other criteria that correlate with high activity in that particular fishery (e.g. depth, distance from shore).
3. *Interviews with fishery participants and managers*: Some fisheries have no logbook or other data that records the locations of fishing. In such cases, WDFW consulted with fishery participants and managers to determine intensity levels and footprints of select fisheries.

WDFW will publish more specific details for the methods behind producing each map (Washington Department of Fish and Wildlife, 2017). WDFW considers the maps produced by all three methods to advance public knowledge of where fisheries use the Study Area. At the same time, the maps are subject to uncertainty stemming from limitations in the source data and from variability in the fisheries themselves. Data limitations aside, fishing patterns change for a variety of reasons. Changes in regulations, the environment, economic conditions, and more can all change the level and location of fishing effort. Area of high importance may shift from one year to the next, and past patterns may not be reflective of future conditions.

In addition, WDFW emphasizes that the maps' intensity rankings do not represent conflict with or impact from potential new uses in the same area. Although impact would be expected to be proportional to fishing intensity, conflicts in areas ranked as "low" intensity could still cause unacceptable harm to a fishery. Conversely, potential conflicts in areas ranked as "high" intensity might be avoidable or otherwise mitigated. While the presented fishery maps will be helpful in assessing which fisheries may be affected by future project proposals, understanding potential conflict and impact will require consideration of all available information.

Commercial Fisheries

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

The core information on commercial fishing activity comes from fish receiving tickets, commonly referred to as "fish tickets." These tickets are a record of the transaction between a vessel owner or operator that is 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. This database is also shared with state and federal fisheries management agencies through the PSMFC Pacific Fisheries Information Network (PacFIN) database, along with data from Oregon and California.

Table 2.4-8 describes commercial fishing activity for the four coastal counties that are the focus of this section. While the focus of this section is on the landings and revenue by fishery to each county or port, additional information on the impact of these fisheries by community (e.g. jobs, contribution) can be found in the section titled "Economic Impact of Commercial and Recreational Fishing." Grays Harbor and Pacific Counties have been the most active based on all participation metrics (Table 2.4-8). 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 2.4-9). Commercial fishermen residing outside of the Washington coastal county region also fish in the MSP Study Area and use coastal ports.

As Table 2.4-9 shows, there were over 230 vessels registered to Washington residents residing outside of the Pacific coast region, accounting for more than $23.5 million in ex-vessel revenue 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, Baker, Waters, Wegge, & Wellman, 2015). Table 2.4-10 summarizes the total landings, ex-vessel revenue, and price of each species management group landed within the Washington coastal counties.

Of note, by longstanding convention WDFW has recorded the port of landing on fish tickets indirectly by using the principal buying location that fish buyers list on their licenses. However, buyers can and do purchase fish in different ports. For example, a buyer may list his or her buying location as Port Angeles but may also purchase fish in Neah Bay. If so, their Neah Bay purchases will be recorded as having occurred in Port Angeles. This convention inserts some degree of unavoidable inaccuracy when considering landings by port.

Table 2.4-8. Landings, ex-vessel revenues, and participation by county for Washington coast commercial fisheries in 2014. Source: WDFW as reported in Taylor et al. (2015).

County[7]	Round weight (1,000 lbs.)	Ex-vessel revenue ($1,000)	Number of dealers	Number of vessels
Clallam[8]	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 2.4-9. 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[9]	299	40,439
Other Washington	232	23,657
Oregon	72	13,143
Elsewhere	90	13,326
Unknown	7	1,058
No vessel ID	-	1,344
Total	700	92,967

[7] There have been no non-tribal commercial fishery landings recorded in Jefferson County ports along the outer Washington coast since 2007.
[8] Includes Neah Bay, Sequim, and Port Angeles which are located outside the MSP Study Area.
[9] Vessel owner's address is in one of the five Washington coast counties.

Table 2.4-10. Landings, ex-vessel revenue, and average revenue per pound in Washington coastal ports by fisheries management group, non-tribal fishery sector. Includes 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 lb. in 2014	Revenue per lb. (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[10]	282	103	282	560	182	589	1.98	1.86
Other[11]	1,444	268	2,833	1,769	512	2,832	1.23	1.01
Total	129,360	-	-	92,967	-	-	-	-

Groundfish

The fishery sectors described here are grouped together largely 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

[10] 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 only razor clams commercially harvested in the Study Area.

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

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 Thornyhead.

In aggregate, the groundfish fisheries provide some of the largest annual landings into coastal ports (Table 2.4-10). 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.

Though often described together because they are managed under a single Groundfish FMP, there are distinct fishery sectors that operate in the Study Area. These sectors use different fishing methods, fishing grounds, and target different groundfish 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"). Within the category of non-whiting trawl, a third distinction can be made between vessels that use bottom trawl gear and vessels that use midwater gear to target rockfish off the seafloor. Lastly, another distinction can be drawn between the at-sea sector, where catch is processed aboard vessels, and the 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. This 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 pounds to 1.7 million pounds, and earnings ranged from $2.1 million to $5.8 million in revenues. Sablefish is highly valued as seafood and has 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 in some years has been greater than that paid for Dungeness Crab. In 2014, at least 37 vessels recorded at least $1,000 of landing value in this sector, with 29 vessels receiving $10,000 or more.

Fixed gear vessels target sablefish throughout the West Coast. However, 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 18). Off Washington, fixed gear vessels have been required to fish seaward of 100 fathoms since 2002 because of the need to reduce the catch of Yelloweye Rockfish. The fish are targeted using baited hooks or pots that are linked on longlines 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 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 for the use map for this sector (Map 19). 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 19). The midwater targeting strategy focuses on schooling rockfish, primarily Yellowtail Rockfish and Widow Rockfish, and occurs on the continental shelf. Because this fishery was depressed from 2004-2014 in comparison to historical levels due to measures taken to rebuild Canary and Widow Rockfish stocks, no maps were produced for this fishing strategy. Midwater trawling has rebounded some since 2011. It is expected to increase further because both Canary and Widow stocks have been rebuilt, resulting in increased allowable harvests.

Overall, non-whiting trawl accounted for between approximately 1.1% and 3.8% of total Washington coast landings during 2004-2014. Ex-vessel revenue value ranged from $0.6 million to $1.4 million during that same period. Sablefish earns the highest ex-vessel value per pound among trawl fishery species, although Petrale Sole is a highly valued species as well. The management changes made by PFMC in the 2000s to rebuild overfished rockfish stocks and reduce fishing capacity substantially reduced Washington's bottom trawl fleet. This included the groundfish "buy back" program, which aimed to reduce the number of permits by 50% throughout the West Coast. Washington's fishing communities were disproportionately affected. Bellingham area ports were particularly affected, losing all nine bottom trawl vessels. The MSP Study Area still provides important fishing grounds for the Astoria-based (Oregon) bottom trawl fleet, which is the most active trawl port on the West Coast. The majority of non-whiting groundfish landings in Washington occur in Pacific County, Whatcom County (Puget Sound), and Grays Harbor County.

Whiting

As noted above, the fishery for Pacific Whiting includes 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 Washington and Oregon. The amount of whiting caught off Washington varies from year to year, particularly in the at-sea sector (Table 2.4-11). Shoreside vessels 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 regions of the Study Area are key fishing grounds (Map 20). Avoidance of salmon and rockfish bycatch has been a key influence on where the fishery occurred between 2004 and 2014. Bycatch constraints have pushed 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 from this fishery have consistently constituted 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 they were 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 divides 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 2.4-11. Total coast-wide 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 2005-2014 (metric tons)		Washington share in 2014	Estimated portion of Washington share 2005-2014	
		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, with an 11-year average of $2.18 per pound. The total value of the fishery, however, is limited by low allowable catches relative to fisheries like Dungeness Crab and Pacific Whiting (see Table 2.4-10). Commercial salmon fisheries have decreased greatly from historic highs primarily because of population declines across several salmon runs, major changes in how salmon harvests are shared with the treaty tribes following the Boldt Decision in 1974, and other factors (see Tribal Fisheries Section below and Section 1.6 for details on treaty rights). Salmon fisheries are intensively managed by the State and treaty tribes on an annual basis.

Two distinct sectors fish commercially for salmon in the MSP Study Area: the ocean troll fishery and the gillnet fishery. PFMC manages 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 larger, complex salmon management processes that involve the three West Coast states as well as Alaska, Idaho, Canada, and the many 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 wild stocks of high conservation concern.

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 of 20 to 80 fathoms north of the Queets River, and depths of 20 to 60 fathoms south of the Queets River (Map 21). 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 an average of $4.30 per lb. in 2014 and an 11-year average of $4.08 per lb. The number of licenses issued to ocean troll vessels by WDFW 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

Gillnet fisheries operate in Willapa Bay, Grays Harbor, and the Columbia River.[12,13] 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. 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 to 195 for Willapa Bay and from 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 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. It is one of the few fisheries on the West Coast in which participation is still open to entry from new fishers. Albacore are caught off Washington by both local and other West Coast-based vessels using troll and/or pole and line fishing ("bait boat") techniques. Canadian vessels also fish in U.S. waters and make landings in Washington under a treaty between the U.S. and Canada.

The fishery occurs in the summer and fall when the fish migrate to the West Coast. While most of the fishing occurs outside the MSP Study Area, fishing within the Study Area is most common between 30 and 50 nautical miles offshore but sometimes occurs closer in, to 20 nautical miles (Map 22). 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. between 2004 and 2014. Ex-vessel values ranged from about $11.3 to $28.2 million during that same 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 2.4-10). 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

PFMC's coastal pelagic species (CPS) FMP includes 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

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

nearshore including in state waters, Willapa Bay, and Grays Harbor. Anchovies are generally used for bait, and most anchovies are landed in Grays Harbor.

The CPS fishery has brought in relatively high landing volumes (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. This volatility is driven by Pacific Sardine, with landings as low as 9.7 million lbs. between 2004 and 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 2.4-10). 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

When the Pacific Sardine population is large enough to support harvest, fishing takes place in late spring and summer months when water temperatures warm and the sardine migrate into the area. However, state waters are closed to harvest by state law. Grays Harbor County received about 75% of the ex-vessel revenues from sardine on average over 2004-2014. Similar to the groundfish fishery, boats based out of Astoria can take a large portion of their harvest in the Study Area. Washington's share of coast-wide sardine harvest increased later in the 2004-2014 period. This was due to the changing focus to squid in California and the proximity of the fish to Westport (Map 23). However, the Pacific Sardine fishery was closed by PFMC in 2015 because the stock biomass had dropped below a threshold limit, and the fishery remains closed in 2017. The stock is known to fluctuate in abundance based largely on environmental factors and may rebound above the limit if 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 between 2004 and 2014 (Table 2.4-10), 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 exhibited 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 outside the surf line, or approximately 18 feet, to 600 feet (3 to 100 fathoms). Each pot is individually "fished," although pots are often laid out in "strings" that may be up to several miles long. Crab are harvested along the entire Washington coast, including inside Grays Harbor, Willapa Bay, and the Columbia River. However, the most intensive fishing takes place in the southern third of the MSP Study Area, south of tribal U&As (Map 24). The primary landing ports and processing facilities are in Westport, Chinook, Tokeland, South Bend and Ilwaco.[14] Neah Bay[15] and La Push on the northern coast are minor ports for crab, and

[14] The Ports of Chinook and Ilwaco are located inside the Columbia River and outside of the MSP Study Area.
[15] Neah Bay is located outside of the MSP Study Area.

product landed there is typically sent elsewhere for processing. Growth in this aspect of the industry drives increasing prices and economic benefits to 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. Coast-wide coordination occurs on several issues, including a tri-state agreement negotiated through PSMFC which establishes procedures for opening the season. As with salmon, the Dungeness Crab fishery is intensively managed by WDFW and the coastal treaty tribes each year to ensure consistency with the U.S. v. Washington treaty rights decisions.

Co-management of the crab fishery began much later than that of the Salmon fishery, with major changes in the fishery occurring in the mid- to late- 1990s. During the first half of the 2004-2014 study period tribal catches showed a strong increasing trend, both in terms of absolute amount and percentage of the total harvest, as tribal fisheries built up capacity. Co-managers began to achieve target sharing levels within the U&As in the second half of the study period. The main tools for sharing catch have been 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.

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 results in a race for crab, where the bulk of the harvest is taken 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, state and tribal agreements have kept areas north of Klipsan Beach closed to the non-tribal commercial fishery until January. With these delays, there has been some shift in effort to areas in the south that open earlier. Furthermore, WDFW may close the fishery for other reasons, like high levels of biotoxins such as domoic acid, to ensure a safe product in the marketplace. Most recently, elevated levels of domoic acid in Dungeness Crab necessitated a partial closure of the fishery in 2015.

Pink Shrimp

Pink (a.k.a. "Ocean") Shrimp are caught using trawl gear that is designed to fish slightly above the seafloor. Most shrimp trawl vessels are "double-rigged" meaning 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 a season that runs from April 1 to October 31 annually (Map 25). 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.

Because Oregon-based fishing vessels also fish in the MSP Study Area, WDFW manages and coordinates regulation of the Pink Shrimp fishery with the Oregon Department of Fish and Wildlife. Volumes of shrimp landings have increased since 2012 with 30.5 million lbs. landed on the Washington coast in 2014. This was more than twice the amount landed in 2013. Ex-vessel revenues have similarly been increasing, with $1.9 million earned in 2007 and $16.4 million earned 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 2.4-10). 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 in 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, beginning 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. It 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 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. or 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).[16]

Razor Clams

The commercial Razor Clam fishery occurs from May through June each year. In Washington, harvest is limited 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. Most 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 or Grays Harbor Counties.

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

Pacific Halibut fisheries are managed under the PFMC's Pacific Halibut Catch Sharing Plan (CSP) for Area 2A (Pacific Fishery Management Council, 2017).[17] 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. 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 coast-wide. 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. While a commercial Pacific Halibut map is not available, the area north of Point Chehalis on Map 18 for the Sablefish fixed gear fishery and Map 21 of the salmon troll fishery provide the footprint of where the

[16] Seattle, Neah Bay, and Port Angeles are located outside the MSP Study Area.
[17] Area 2A is comprised of the area off the coasts of Washington, Oregon, and Northern California.

incidental fishery may occur. Vessels that participate in the salmon troll (Map 21) and Albacore troll (Map 22) fisheries south of Point Chehalis generally participate in the directed commercial fishery.

Hagfish

The commercial Hagfish (aka slime eel) fishery began 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 the number active in any given year ranging from fewer than 3 to all 15. This fishery is open year-round, and uses pot gear on muddy or sandy bottom in 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 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.[18] 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 2.4-12 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 recreational fisheries. A single fishing trip might include several of what are described here 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[19] for certain species like salmon. Anglers also fish from shore for species like Redtail Surfperch and from jetties for species like Lingcod, but 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 recreational fisheries in 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 samples the catch from a portion of them on random

[18] Ilwaco, Port Angeles, Port Townsend, and Blaine are located outside the MSP Study Area.

[19] Recreational fishing occurs in Willapa Bay and Grays Harbor estuaries. However, while maps were 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.

days of the week. This information on fishing effort (“angler-trips”) and catch is 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 boat-based fishing but also samples anglers fishing from certain jetties.

Boat-based recreational fishing has two distinct components: a charter boat or “for-hire” fleet carrying paying passengers and a “private boat” fleet where anglers fish aboard vessels they rent or own. On average over the past decade, charter vessels carried approximately 32% of anglers making fishing trips while 66% of anglers were on private vessels (Table 2.4-12). Charter boats and private vessel activity varies by species caught and port location. Westport and Ilwaco have had the largest charter boat operations (Table 2.4-12).

The Washington charter boat industry has been a major part of coastal communities for decades. The industry developed rapidly after World War II, with the focus exclusively on salmon through the 1960s and Westport billing itself as the “Salmon Fishing Capital of the World.” Businesses have since diversified their portfolio of trips and now target bottomfish, Albacore, and Pacific Halibut. Charter boat activity has been relatively stable since the 1990s, but remains below the historical peak in the 1970s (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 second most frequently targeted species group (Table 2.4-13). A comparison of the number of trips made between 2004 and 2008 with those made between 2009 and 2013 shows that the average number of charter boat trips annually has decreased by about 8%. Comparing those same time periods, the numbers of trips targeting Pacific Halibut, salmon, and bottomfish have declined while Albacore trips have increased.

Table 2.4-12. 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)[20]

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[21]	-	-	-	-	-	1,783
Total[22]	52,711	36,351	32,881	8,192	15,461	147,389

[20] Ilwaco, Neah Bay, and Chinook are located outside the MSP Study Area.
[21] North Bay jetty area of the Columbia River.
[22] Totals may not add up to 100% due to rounding.

Table 2.4-13. 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%

On average, private vessel anglers launch primarily from Neah Bay (30%), Ilwaco (27%), and Westport (20%) (Table 2.4-12). 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 2.4-14). Cascade Economics (Taylor et al., 2015) reports a recent trend toward larger private vessels capable of traveling farther offshore.

Table 2.4-14. 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%
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 2.4-15. Catch, trends, and management for each species group are discussed below.

Table 2.4-15. Average annual sport catch in marine waters[23] 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[24]
Salmon[25]	105,077
Sturgeon[26]	378
Pacific Halibut	7,613
Bottomfish[27]	277,912
Razor Clams	3,129,482

Salmon

The recreational salmon fishery occurs in Willapa Bay (and into the Willapa River), 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 2.4-13 and Table 2.4-14), and are the second highest finfish in terms of average catch between 2007 and 2012 (Table 2.4-15). 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% were caught in the area near Cape Flattery (WDFW Marine Area 4a). The species of salmon caught 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). Areas of high and moderate ocean salmon fishing intensity are shown in Map 26. 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 within three miles 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 evolutionarily 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 sizes, and season dates, all of which vary by Marine Catch Area.

[23] Marine areas include coastal streams, which are outside of the MSP Study Area.
[24] Numbers represent the number of fish caught or clams dug.
[25] Salmon totals include all species, including Coho and Chinook.
[26] Sturgeon total includes only fish caught in coastal streams.
[27] Bottomfish include all rockfish species and other bottomfish.

Bottomfish

The recreational bottomfish fishery represents the largest recreational finfish fishery by average number of fish caught annually (Table 2.4-15). The bottomfish fishery is also the second most popular recreational finfish fishery in terms of number of trips taken for targeted species for both charter boat and private boat fishing (Table 2.4-13 and Table 2.4-14, respectively). Primary targets within this fishery are rockfish and Lingcod, with Black Rockfish being the main target. Other bottomfish species targeted or kept include 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 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 most private vessels. The fishery has been relatively stable over time (Industrial Economics Inc., 2014; Taylor et al., 2015). Areas of high and moderate recreational bottomfish fishing activity in the MSP Study Area are shown in Map 27.

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 of 7,613 fish caught per year from 2007/08 to 2011/12 (Table 2.4-15). The North Coast ports of Neah Bay[28] 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). Areas of high and moderate recreational halibut fishing activity in the MSP Study Area for halibut are shown in Map 28.

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).

WDFW manages its recreational fisheries by three subareas: North Coast, South Coast, and the Columbia River. The fishery is managed through quotas (based on the CSP described above under Commercial Pacific Halibut), 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 these fish migrate into the area. As with the commercial fishery, the fish tend to be available between 20 and 100 nautical miles offshore (Map 29). 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 2.4-13 and Table 2.4-14). Substantial increases in 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.

[28] Neah Bay is located outside the MSP Study Area.

Razor Clams

The coastal 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. Between 275,000 and 460,000 seasonal digger trips result in the harvest of as many as 6.1 million clams. The fishery generates between $25 and $40 million 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[29] (Map 30).

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. 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.

Openings 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 number of harvestable clams by area, and ends 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.

Dungeness Crab

The Dungeness Crab recreational fishery is one of the most popular in the state, but mainly occurs in Puget Sound. 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 employment and income within their communities as well as for ceremonial and subsistence purposes. It is important to note that tribes rely on fisheries for cultural and spiritual reasons that go beyond any measurable or quantifiable value. As noted in

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

the introduction to this section, 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 section 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 (the Makah, Quileute, and Hoh Tribes and the Quinault Indian Nation) are co-managers of fisheries resources with the state of Washington and/or federal agencies. Federal courts have ruled that the treaty tribes have the right to 50% of the harvestable resources passing through their respective treaty areas, generally referred to as their "usual and accustomed areas", or U&As (*U.S. v. Washington*, 384 F. Supp. 312 (W.D. Wash. 1974), *U.S. v Washington*, 873 F. Supp. 1422 (W.D. Wash. 1994)). Each treaty tribe regulates the fishing activities for its members within their respective U&As in accordance with tribal law and judicially prescribed fishery management responsibilities, maintains its own fisheries management and enforcement staff, enters into management agreements with other co-managers, and engages in a wide variety of research, restoration, and enhancement activities to improve the scientific basis for resource stewardship

The treaty tribes also participate in the PFMC process, where these four tribes and other West Coast tribes participate in committees and are represented by a voting member on PFMC. PFMC does not set management regulations for the tribes, as each tribe manages its own fishers directly. Catch sharing and other management measures are negotiated with state, federal, and tribal co-managers through forums that can differ fishery by fishery (see Section 1.6: Pacific Coast Indian Tribes and Treaty Rights). The tribal fisheries profiles below summarize available information on fishing activities and economic impacts for each of the four coastal treaty tribes.[30]

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. They include five species of salmon, groundfish, and shellfish (Table 2.4-16). The salmon gillnet fishery occurs along the shore near Cape Flattery and in the Strait of Juan de Fuca, while other fisheries occur offshore of the north coast of the Olympic Peninsula within the MSP Study Area (Taylor et al., 2015).

Table 2.4-16. 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)
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)	

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

Currently, about 70 tribal fishing vessels are operating out of Neah Bay (Makah Fisheries Management, 2017). 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. This value does not include catch by tribal fishers that was not delivered to Neah Bay. The Makah tribe also participates in the Pacific Whiting fishery, in which fish are either processed at sea or delivered to Westport. As a result, the ex-vessel values reported understate the total Makah tribal fishery ex-vessel value (Taylor et al., 2015). Makah's participation in the whiting fishery contributes an additional estimated $4 million in ex-vessel value, when active (Makah Fisheries Management, 2017). Combined, Makah tribal fisheries support more than 50 percent of the economy of Neah Bay (Makah Fisheries Management, 2017).

Table 2.4-17. Average Makah Tribe harvest by fishery, 2011-2015. (Makah Fisheries Management, 2017)

Fishery	Average 2011-2015 harvest (thousands of lbs.)
Salmon	425
Whiting	7,636
Groundfish	3,203
Halibut	130
Shellfish	81
Total	11,474

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. The tribe regulates its own fisheries. It sets season length, catch, and other restrictions and shares this information 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. The Quileute and the State negotiate agreements annually for sharing of the available harvest of crab within the Quileute U&A. In recent years "Special Management Areas" that provide exclusive access to tribal fishers for a period of time have been an important tool for co-managers.[31]

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 2.4-18). The tribe has shown growing interest in Pacific Whiting, although has not fished whiting to date. 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).

[31] 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

Table 2.4-18. 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[32]	
		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 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 were about $9.2 million (Table 2.4-19). 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).

[32] Data from 2010 is not included.

Quinault continues to develop other treaty fisheries within its ocean U&A including Pacific Whiting, tuna, Hagfish, Spot Prawns, Pink Shrimp, and others.

Table 2.4-19. 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[33]	$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 in the Study Area target and gain economic benefits from many of the same fish and shellfish populations. This section describes the different manners in which commercial and recreational fisheries produce those benefits, and summarizes their estimated economic contributions to the coastal and state economies. The Cascade Economics study produced these estimates (Taylor et al., 2015), which 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. These variations result from many 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 Cascade Economics report was produced specifically to inform the MSP and so is the focus of this section. Other studies focusing on the coast have been produced for various purposes but are not discussed here.[34] Economic studies use data, assumptions, models, and

[33] Combined halibut, sablefish, lingcod, rockfish, and sardine fisheries.

[34] Additional economic baseline studies include but are not limited to:

- Butler, K., Fryday, C., Gordon, M., Ho, Y., McKinney, S., Wallner, M., & Watts, E. (2013). Washington's working coast: An analysis of the Washington Pacific coast marine resource-based economy (Keystone Project). University of Washington Environmental Management Certificate Program. Available at: http://media.wix.com/ugd/e2eea5_7a4796fc90c3f86ff0ae22e675bd6b55.pdf
- Radtke, H. (2011). Washington State Commercial Fishing Industry Total Economic Contribution. Prepared for Seattle Marine Business Coalition. Available at: http://www.philipspublishing.com/smbc/attachments/SMBC%20Washington%20Total%20Commercial%20Fisheries%204.pdf.

other methods to produce estimates of economic activity. Studies that differ in data, assumptions, methods, and input data will produce different estimates. Therefore, while the Cascade Economics report provides an informative picture of how fishing contributed to economic activity in 2014, its estimates should be recognized as involving uncertainty.

"Direct" economic inputs to state and coastal economies include the revenues earned by fishing operations through the sale, barter or trade of their catch, and those earned by seafood businesses who process and facilitate transactions with restaurants, retailers, and other consumers. The money received by fishing operations for their catch is referred to as ex-vessel revenues, which are commonly used by managers 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. Spending on things like fuel, boat repair and maintenance, gear, and supplies leads to "indirect" effects on the economy, as the businesses providing these goods and services then spend a portion of their revenues on expenses and income. A third type of effect, called "induced" effects, happens as owners and employees from fishing business and supporting industries spend their disposable income throughout the economy.

Seafood buyers and processors are the next direct link in the economic chain. Some fishing operations sell their catch directly to the public at the dock, and some processing businesses own and run their own fishing vessels. However, most fishing operations landing in the state sell their catch to a seafood processing or distribution business. Fish and shellfish from the MSP Study Area are sold into a diverse set of markets. They are sold for uses including 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 are 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, as a dollar of ex-vessel revenue can translate to a much different total economic contribution depending on various factors. For instance, some 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 supports few jobs and may have a lower total economic contribution. 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 be less beneficial to Washington coastal counties. However, the reverse also happens with some landings of seafood in Oregon that are transported to Washington for processing.

- Martin Associates (2014). The 2013 Economic Impact of the Port of Grays Harbor. Prepared for the Port of Grays Harbor. Available at: http://www.portofgraysharbor.com/downloads/reports/Grays_Harbor_Economic_Report.pdf.
- Resource Dimensions (2015). Economic Impacts of Crude Oil Transport on the Quinault Indian Nation and the Local Economy. Available at: http://www.fogh.org/pdf/QIN-Economic-Study.pdf.
- Resource Dimensions (2015). Economic Impacts of Crude Oil Transport on the Grays Harbor Economy. Available at: http://www.fogh.org/pdf/FOGH_Economic_Impacts_Crude_Oil_Transport.pdf.
- National Marine Fisheries Service. (2015). Fisheries of the United States 2014 (Current Fishery Statistics No. 2014). Silver Spring, MD: National Oceanic and Atmospheric Administration. Available at: http://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus14/documents/FUS2014.pdf.

Using their model of the economic linkages[35] outlined above, Cascade Economics estimated that in 2014, 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 2.4-21). 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. Note that depending on the data and methodology used, estimates of total economic contribution from fishing activity may vary between studies.[36]

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) or the effects from the additional distribution and retailing of the seafood landed in the coastal counties. They also do not include 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 that 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 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 report (Taylor et al., 2015).

Table 2.4-20. Total contributions to the five-county[37] coastal region economy from 2014 Washington coast non-tribal commercial fishing and seafood processing by county of the activity. Source: Taylor et al. (2015).

	Coast-wide	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 2.4-21. Total contribution to the State of Washington economy from 2014 Washington coast non-tribal commercial fishing and seafood processing by county of the activity. Source: Taylor et al. (2015)

	Coast-wide	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

[35] Cascade Economics derived economic multipliers using IMPLAN models based on 2012 regional economic data.
[36] See list of additional studies in footnote 26.
[37] There were no non-tribal commercial fisheries landings recorded in Jefferson County in 2014.

In contrast to commercial fishing, recreational fishing is conducted for sport, enjoyment, or personal use, and state law prohibits anglers from selling their catch. The willingness of anglers to spend income to make fishing trips in the Study Area 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, and more also produce indirect and induced economic benefits. 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 affects where economic benefits are received. Anglers traveling into coastal areas 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, benefitting the economy there instead of the coastal economy.

The charter boat industry is a distinct portion of the recreational fishing sector. Owners and crew receive trip related expenditures in the form of fees and tips that anglers pay when taking trips aboard charter vessels. Because 100 percent of charter boat 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 (Taylor et al., 2015).

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 million statewide (Table 2.4-22). 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 2.4-23). Labor income includes money and benefits paid to employees as well as the earnings of owners and the self-employed. It is of note that 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 recreational fishing's economic contribution to the state and coastal economies, but Cascade Economics reports that they are very difficult to estimate accurately.

Table 2.4-22. Trip-related expenditures associated with ocean sportfishing trips in 2014 from charter vessels, private vessels, and shore and jetty fishing 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 2.4-23. 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 in Puget Sound. These ports provide infrastructure like moorage and access (e.g. boat ramps) for commercial and recreational fishing vessels. They also provide 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 31. Additional discussion of Ports is in Section 2.7: Marine Transportation, Navigation, and Infrastructure.

Clallam County ports

Neah Bay

Neah Bay is the largest commercial fishing port in Clallam County and is also home to the fishing fleet of the Makah Tribe, 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. On average over 3,000 charter boat trips were taken from Neah Bay annually during 2004-2013. Almost 30,000 trips were taken annually by private vessels during that same time period, on average (Table 2.4-12). Neah Bay serves as the primary private boat marina supporting the greatest average number of 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, but the port also supports non-tribal commercial and recreational fisheries. The port has a seafood processing plant onsite. Data confidentiality limits the reporting of non-tribal fishing into 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 per year from 2004-

2013. The annual average number of private vessel trips from La Push was about 7,051 during that same period (Table 2.4-12). 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 for 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. Approximately 20,020 average annual private vessel trips were taken during that same period (Table 2.4-12) (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 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). Commercial fisheries landing in Ilwaco/Chinook primarily target groundfish, salmon, Dungeness Crab, Albacore Tuna, 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 2.4-12). In Ilwaco, 10,171 charter boat trips were made per year on average between 2004 and 2013, with 26,181 private vessel trips made per year on average during that same time period (Table 2.4-12) (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 many as 17 vessels were 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 significantly influence the participation and economics of these industries. While no predictions can be made for certain, primary factors are summarized below to provide insight into the future trends and challenges of these industries.

Barriers to Participation in the Commercial Fishing 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 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 even to 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 cause 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 hotels, restaurants, 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 were noted above. For instance, the salmon, Dungeness Crab, and groundfish bottom trawl fisheries all saw major declines from historic highs in the 1980s and 1990s. Legal and regulatory changes were the major causes of these declines. Looking ahead, some degree of uncertainty in fisheries management and available quotas will be unavoidable given natural fluctuations in fish populations and uncertainty in stock assessments. This uncertainty is expected to continue affecting fishers and processors who may be considering making capital investments (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 types of 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 on 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 west coast of the U.S. 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 fishing, 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. 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, spawning runs, and prey availability), 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 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 cause significant uncertainty when forecasting future trends. What is certain, however, is the importance of this industry to the economy and social identity of the coastal communities adjacent to the MSP Study Area, and to the state of Washington. To coastal residents, losses within these fishing sectors could mean a loss of jobs, income, and a cultural way of life, for both 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 (United States Department of Agriculture, 2014). The industry has a long history within the region and has adapted to several challenges to sustain and thrive. Current challenges such as invasive and nuisance species management, regulatory complexities, and climate change will continue to influence the future of aquaculture.

This section summarizes the history and current use, economic impacts, related infrastructure, and future trends of shellfish aquaculture in the MSP Study Area.

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 2013 ranks Washington first in value of sales of farmed mollusks ($149.3 million) accounting for 45% of the value of U.S. farmed mollusk production (United States Department of Agriculture, 2014).

Aquaculture in the MSP Study Area consists exclusively of shellfish culture and occurs primarily in Willapa Bay (Pacific County) and to a lesser extent in Grays Harbor (Grays Harbor County). Nearly all 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).

In 1895, Washington passed the Bush Act and the Callow Act which allowed for the sale of state-owned tidelands into private ownership for shellfish cultivation. Under the Bush and Callow Acts, 7,054 acres in Grays Harbor and 25,511 acres in Willapa Bay were sold into private ownership (Washington State Department of Natural Resources, 2017b). Aquatic lands that were retained by the state may be available for lease. Currently, approximately 21,000 acres of state-owned aquatic lands are under lease for aquaculture throughout the state, with around 80% being used for commercial oyster cultivation (Washington State Department of Natural Resources, 2017a). The state also established oyster reserves in 1890, of which there are currently about 10,873 acres with the majority located in Willapa Bay (Dumbauld, Kauffman, Trimble, & Ruesink, 2011). The reserves were retained in the public domain to provide seed and an exploitable stock of oysters.

Native Olympia Oysters (*Ostrea lurida*) originally dominated Willapa Bay and Grays Harbor. Willapa Bay had a large industry based on the harvest of the Olympia Oyster, but by 1920 it had almost completely ceased. The first trade in oysters from Willapa Bay to San Francisco via schooner began in 1850 (Blake & Zu Ermgassen, 2015). Natural intertidal oyster beds were harvested by hand and transported to culling stations at higher tidal elevations where

[1] Shellfish aquaculture is also important to the coastal tribes for sustaining cultural and subsistence uses and providing commercial opportunities. Tribal shellfish aquaculture activities are not discussed in this section.

they were sorted. The remaining shells and undersized oysters were deposited onsite rather than being returned to the natural beds, which then hindered recruitment. There were also severe losses of bedded oysters due to freezing weather. This continued to occur throughout the late 1800s along with increased spatial competition from eelgrass. In 1899 the state authorized dredging for oysters, which allowed the harvest of deeper subtidal beds (Blake & Zu Ermgassen, 2015).

As a result of these factors, stocks have been depleted and there has been only occasional trade in Olympia Oysters since 1913. Production has shifted to the Pacific Oyster (Blake & Zu Ermgassen, 2015). Although harvest pressure has been negligible for over 80 years, Olympia Oysters have been unable to recover to their former population levels and status in Willapa Bay (Trimble, Ruesink, & Dumbauld, 2009). There are many potential contributing factors to this inability to recover, including increased mortality from exposure to air, competition from fouling organisms, recruitment preference for Pacific Oyster reefs (Trimble et al., 2009), and spatial competition from eelgrass (*Zostera marina*) (Blake & Zu Ermgassen, 2015).

Pacific Oyster (*Crassostrea gigas*) spat was transplanted from Japan starting in 1928. As importation of Pacific Oyster seed continued, the Pacific Oysters began to spawn naturally in Willapa Bay, but not at rates capable of fully supporting the industry. Imports continued until the mid-1970s when hatchery technology began to successfully produce Pacific Oyster larvae, providing a more stable seed production method. 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 notable 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 Harbor since the early 1990s and *S. densiflora* was discovered in Grays Harbor in 2001. Spartina is an aggressive plant that disrupts estuary ecosystems 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 led by the Washington State Department of Agriculture (WSDA) in partnership with the Washington Department of Natural Resources (DNR), the Washington Department of Fish and Wildlife (WDFW), the Washington Department of Ecology (Ecology), local governments, tribes, the United States Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), and private landowners has been extremely successful at the reduction and control of Spartina. Control methods include herbicide application 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. In order to maintain the program and prevent a resurgence of Spartina along the coast, resources continue to be dedicated to this purpose and surveys and removal treatments are ongoing (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 cause beds to become too soft to support oysters and aquaculture equipment. This has a dramatic economic influence on the aquaculture industry.

The pesticide carbaryl has been 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 of controlling burrowing shrimp (Booth, 2007). Some growers are pursuing the use of an alternative pesticide, imidacloprid, to replace carbaryl and effectively control the expansive populations of burrowing shrimp. Managing these species will continue to be a major challenge for the industry in 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. These products primarily include oysters and Manila Clams. According to WDFW data for 2013, Pacific Oysters account for about 82% of the shellfish farmed and harvested in Pacific and Grays Harbor Counties. Manila Clams account for 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 2.5-22.5-2) (Industrial Economics Inc., 2014).

Pacific County produces more shellfish than Grays Harbor County. Harvest and value have varied over time (Table 2.5-1). Production data suggest that over the past 10 years, there has been a general decrease in Pacific Oyster harvest[2] and a general increase in Manila Clam harvest (Industrial Economics Inc., 2014). Due to challenges associated with accurate and comprehensive reporting within the industry, WDFW recognizes that these numbers may underrepresent actual harvest. While WDFW data may not reflect true production values, they are currently the best available data for illustrating aquaculture production status and trends (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. 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).

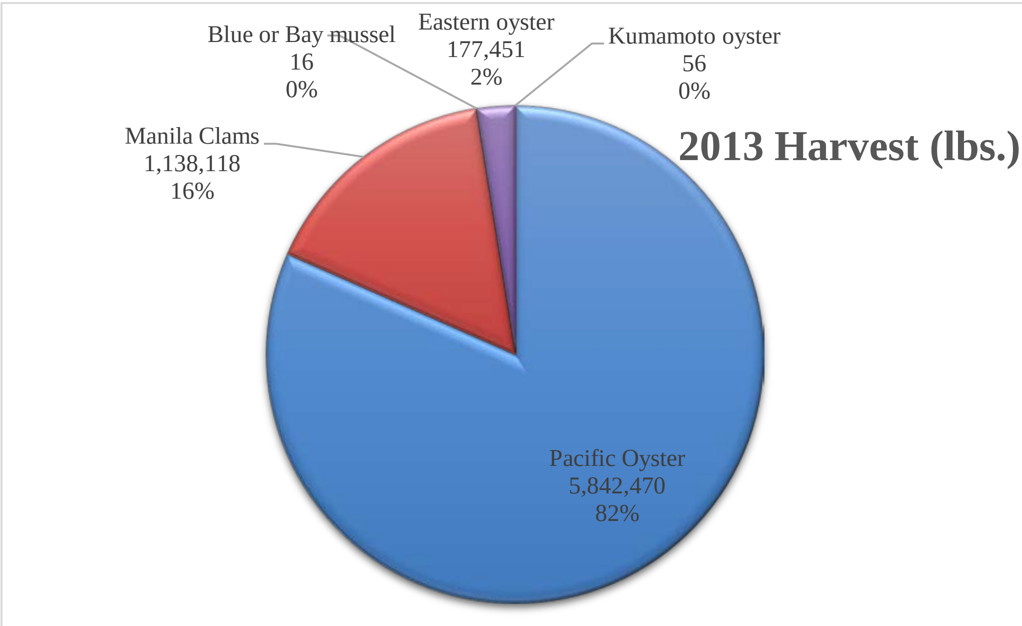

Figure 2.5-1. Relative harvest (round lbs.) of farmed shellfish products in Pacific and Grays Harbor Counties, 2013. Source: Industrial Economics (2014).

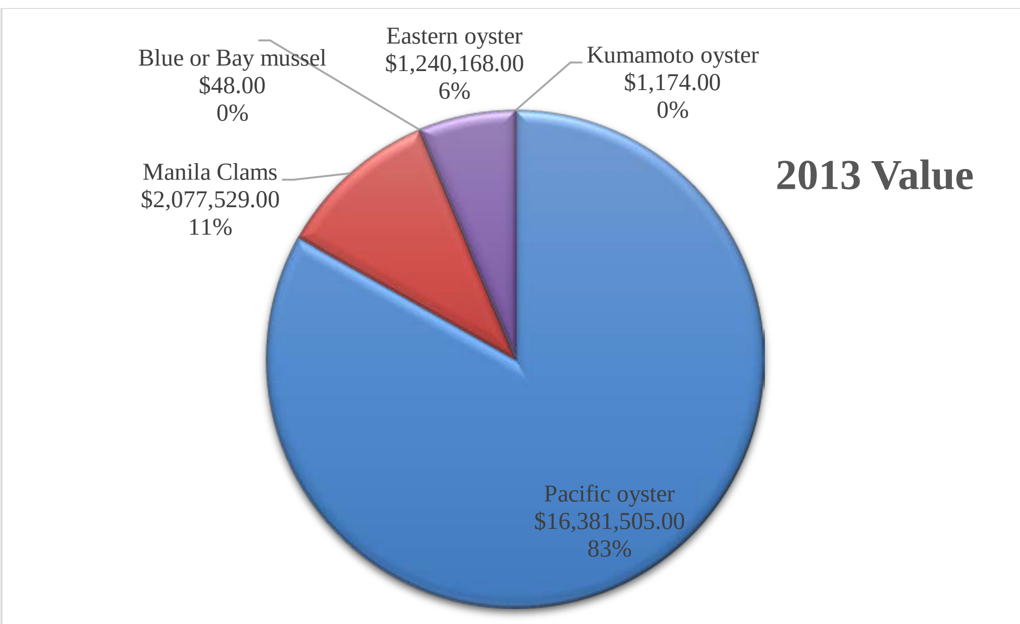

Figure 2.5-2. Relative value (dollars) of farmed shellfish products in Pacific and Grays Harbor Counties, 2013. Source: Industrial Economics (2014).

Table 2.5-1. High and low values for harvest (round lbs.) and value (2014 $) of Pacific Oyster and Manila Clam aquaculture 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 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 in 2012. Grays Harbor ranked 7th statewide, and 43rd nationally. 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 state sales[3] (Industrial Economics Inc., 2014).

Reporting challenges make it difficult to derive consistent, representative participation numbers in the aquaculture sector. 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. Numbers of farms can fluctuate on a regular basis and are not always consistent with WDFW estimates, which reported 20 farms in Willapa Bay and 6 farms in Grays Harbor in 2012. These inconsistencies are 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). The Washington Department of Health (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 publicly owned tidelands in Willapa Bay and Grays Harbor. Commercially farmed acreage for aquaculture is estimated to total 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 number 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 one-half and two-thirds 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. About 1,000 acres of these reserves are currently used for oyster production and allow licensed individuals to harvest

[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 variation in sales and production numbers between reports.
[4] Estimate ranges are based on WDFW data compared with grower survey data.

naturally occurring oysters (WDFW personal communication, May 23, 2016). Spatial use of the estuaries by the shellfish aquaculture industry is represented in Map 32.

Oyster production can be accomplished using natural (a.k.a. wild or natural 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. Tanks contain warmed water and are filled with bags of oyster shells onto which the larvae settle. After five to ten days, the shells with the settled larvae (a.k.a. “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 reaching harvest size (Industrial Economics Inc., 2014). The vast majority (approximately 95%) of oysters cultured in Willapa Bay and Grays Harbor use bottom culture methods, though some oysters are cultured using off-bottom techniques such as longlines, flip bags, and racks and bags. 100% of Manila Clam crops rely on bottom culture techniques. (B. Sheldon, personal communication, May 26, 2016).

Oysters are sold in-shell or processed by shucking. 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, large 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, meaning 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 set by the National Shellfish Sanitation Program for water in which shellfish fisheries and aquaculture operate, these coastal areas often have amplified environmental monitoring. 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, 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 • Authorizes in-state and out-of-state shellfish importation and transfer
Washington Department of Health	• State Shellfish Authority, ensures compliance with the U.S. Food and Drug Administration's 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	• Issue 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 local and statewide economies. However, comprehensive economic impact estimates are particularly challenging to generate for this industry due to discrepancies between data collected by the state and other reports from the industry.

In addition to the data collected by WDFW, further analyses have been conducted to capture more complete information on the economic impact of the industry. Northern Economics, Inc. (NEI) conducted an assessment of shellfish aquaculture in WA, OR, and CA based on a survey of producers and detailed interviews (Northern Economics, Inc., 2013). The study collected data on employment, revenue, expenditures, production, and acres of land in production. NEI then conducted an input-output analysis using the IMPLAN software tool to evaluate the impact of the industry on the Washington economy (Northern Economics, Inc., 2013). Results of the analysis are in Table 2.5-3. Additional details on the IMPLAN analysis and results can be found in the report at: http://www.pacshell.org/pdf/economic_impact_of_shellfish_aquaculture_2013.pdf.

Table 2.5-3. Economic impact of shellfish aquaculture on Washington State in 2010. Source: Northern Economics, Inc., 2013.

Multipliers per dollar	Expenditures	Employment	Labor income
Direct	$101.4 million	1,900	$37.3 million
Indirect	$38.2 million	390	$21.2 million
Induced	$44.8 million	420	$18.6 million
Total	$184.4 million	2,710	$77.1 million

Taylor et al. (2015) built on the study by NEI and data from the state to conduct an additional economic analysis as part of the marine spatial planning process. They conducted a focus group with members of the shellfish aquaculture industry in the coastal counties to evaluate the results of the NEI study. As a result, a few topics were identified for additional analysis.

Taylor et al. conducted a survey and interviews to capture information about the processing and distribution activities of shellfish growers in Pacific and Grays Harbor Counties. Of the 14 companies identified, eight completed the survey. Respondents to the survey reported total sales of nearly $56 million and total expenditures of nearly $56 million in 2014. Expenditures made by the shellfish industry include payments for goods and services such as payroll and benefits, seed oysters, ice, packaging, and taxes. Approximately 71% of expenditures were made in the coastal counties and nearly 94% of expenditures were made in Washington. Including non-respondent processors and distributors, estimated expenditures totaled $59.37 million (Taylor et al., 2015).

To determine the total economic contribution of the shellfish aquaculture industry including harvesting, processing, and distribution, Taylor et al. (2015) analyzed 2013 production data from the state and the surveys from the shellfish harvesting and processing industry. Taylor et al. (2015) determined that the WDFW data was the best available for this analysis. However, this analysis is not directly comparable to the NEI analysis or results discussed above. The total direct expenditures for growing, processing, and distribution of shellfish estimated from the survey and interviews were used. IMPLAN data were used to generate estimates of employment and labor income, including jobs directly provided by shellfish growing and processing as well as jobs generated in the region through indirect and induced activity. Results indicate that about 847 jobs and $50 million in labor income were generated by the aquaculture industry in the Washington coastal region. An additional 383 jobs and $23.2 million in total labor income were generated in Washington State outside of the coastal region by the coastal aquaculture sector's activities (Table 2.5-4) (Taylor et al., 2015). Estimated expenditures, total employment, and total labor income generated by the shellfish aquaculture industry in Pacific and Grays Harbor Counties are presented in Table 2.5-4.

Table 2.5-4. 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).[5]

	Expenditures	Total employment	Total labor income
Washington coastal region	$65.2 million	847	$50 million
Statewide total	$78 million	1,230	$73.2 million

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

At the county level, Pacific County has a particularly 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 experiences reduced business activities or shellfish area closures.

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

Related Infrastructure

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

[5] The results in Table 2.5-3 and Table 2.5-4 cannot be directly compared due to differences in scope and methodology.
[6] 60% of the proceeds from sales of oysters on the reserves go to research activities in Willapa Bay (WDFW, personal communication, May 31, 2016).

Center, Washington. Some other companies are able to produce some larvae for their own operations, but it is often not enough to entirely meet their seed needs. 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 were established in Hawaii 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]. The product can also be processed in-shell (non-living) or be shucked and packed. DOH has different licensing requirements for different categories of shellfish processors (a.k.a. "dealers"). Processors can be licensed to perform various processing and selling activities, such as shellstock shippers or shucker-packers.[8] Several processing companies 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, and Brady's Oysters and Lytle Seafood are the only processers of oysters in the area (Industrial Economics Inc., 2014). 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).

Water Access

Because it is an estuary use, water access is required for the farming of shellfish. Willapa Bay has marinas, such as Bay Center Marina and Nahcotta, that are primarily used by oyster growers to transport and store boats, along with being used for 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 existing 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.

[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 Species Control

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 in Spartina in Willapa Bay is a substantial success story (Washington State Department of Agriculture, 2015), other invasive and native 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*), native 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 of these species on aquaculture production 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 (Taylor et al., 2015). Controlling burrowing shrimp can be quite challenging and costly to the industry, and oyster growers have pursued the use of pesticides as their most effective means of control. Similarly, Japanese eelgrass also requires the use of herbicides for control. The industry must comply with several regulations in order to treat oyster beds with pesticides. This includes obtaining permits from Ecology and following the requirements from the WSDA and the U.S. Environmental Protection Agency (EPA) for registering and labeling the pesticides. 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 challenges the aquaculture industry faces in managing these 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 could 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).

In March 2017, the Willapa/Grays Harbor Oyster Growers Association (WGHOGA) submitted a permit request to Ecology to allow and regulate the use of the pesticide imidacloprid to control ghost and mud shrimp in Willapa Bay and Grays Harbor. If the proposal were approved, it would allow commercial shellfish growers to treat 485 acres of shellfish beds in Willapa Bay and 15 acres in Grays Harbor. Ecology has been working on a supplemental Environmental Impact Statement (EIS) to support an earlier environmental review regarding the impacts of using of imidacloprid on commercial oyster and clam beds in the two estuaries. The supplemental EIS is designed to aid in decisions regarding the proposal. Ecology anticipates making a final permit decision in late 2017 after public comment and further environmental review.

[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.

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 processes such as permit applications, renewals, and reporting requirements; (2) that 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) that 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 increasing water temperature.

Ocean acidification is one of the primary environmental concerns for the shellfish aquaculture industry in the MSP Study Area and elsewhere in Washington. As ocean acidity increases, the calcium carbonate on 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 natural set failures 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 the potential risks to the economy and culture of the aquaculture industry. 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 recommendations of the Blue Ribbon Panel, the Governor and the legislature created the Marine Resources 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 in addressing the consequences of ocean acidification, and are investing for the future in anticipation of further impacts. The Blue Ribbon Panel estimated that ocean acidification has already cost the oyster industry over $110 million. Some companies have opened hatcheries 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).

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

The failure of natural oyster sets (either resulting from ocean acidification or other conditions) creates challenges and increased costs for the oyster industry. One company has seen a five- to six-fold increase in seeding process costs. A natural set failure 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 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 will 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 the occurrence of 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 instances of *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 pathogens in close collaboration with research partners at the National Oceanographic and Atmospheric Administration (NOAA), the Food and Drug Administration (FDA), and academic institutions. 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).

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 are of particular concern (See Section 2.7: Marine Transportation, Navigation, and Infrastructure). Concerns center on the risk of an oil spill, and the potentially severe impact it could have to the industry through contamination of shellfish beds. Another concern for Grays Harbor growers is the deepening of the federal navigation channel (See Section 2.10.3: Dredge Disposal). Past navigational dredging is believed to have contributed to the 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 are sources of additional uncertainty for the future of the aquaculture industry.

Potential new uses addressed within the MSP 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. Risks of finfish aquaculture include reduced water quality in shallow and poorly flushed sites, disease, and escape of cultivated fish (See Section 2.10.2: Offshore Aquaculture). There is currently no commercial net pen aquaculture of finfish within the estuaries. If net pens were constructed 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 commercial, 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 can innovate and adjust to changing climatic conditions and other challenges, such as invasive and nuisance species; if policy makers can address concerns about uses such as crude oil transportation; and if 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 development of production and markets for Manila Clams (Industrial Economics Inc., 2014). Aquaculture is important economically and socially to the coast and to Washington, and will continue to play a role in future policies and decisions related to coastal and marine uses.

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2.6 Recreation and Tourism

Washington's Pacific coast 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 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 totaling $481.2 million in 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 in 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 coast have been designated to protect and facilitate public recreation. For example, Olympic National Park, established in 1938 by President Roosevelt, has three park districts directly on the coast adjacent to the MSP 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). The Act also established much of the southern coast as a Seashore Conservation Area (SCA) for public recreational use and enjoyment.

The coastline in the northern portion of the MSP Study Area (Clallam and Jefferson Counties) has rugged, dramatic cliffs and limited public access points. The Makah, Quileute, and Hoh Indian Tribes have reservation lands in the northern portion of the Study Area, and much of the rest of the northern coast is within Olympic National Park. Recreational features of the northern coast include Cape Flattery; Olympic National Park 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 two large estuaries with calmer waters protected from the open ocean. The southern coastal area contains more than ten state park facilities, the 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).

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

Recreation Activities

A panel survey conducted from 2014 to 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 Washington 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 is used to some extent for recreation (Map 33) (Point 97 & Surfrider Foundation, 2015).

Respondents were asked to identify all 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. 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 recreation along the coast include swimming, beach driving, tide pooling, surfing, kayaking and paddle boarding, SCUBA diving, windsurfing, boating, horseback riding, whale watching, and other activities (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 report by Point 97 & the Surfrider Foundation (2015). Some of these recreational activities are highlighted below.

Wildlife viewing

Wildlife viewing from shore ranked highly as a frequent activity among visitors to the coast in the MSP Study Area. Visitors also participate in wildlife viewing on the water from private boats, 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. Visitors also view marine mammals like whales, seals, otters, and sea lions. The peak season for whale watching is between March and May, when 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, seals, sea otters, humpback whales, 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 to view transient orcas. South of La Push through Kalaloch and Queets the coast provides many more opportunities to view wildlife including whales, brown pelicans, sea lions, harbor porpoise harbor seals, and sea otters.

On the southern 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

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

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, with the peak bird migration typically occurring in late April and early May (Taylor et al., 2015). Thousands of people attend the Grays Harbor Shorebird Festival to view the migration of hundreds of thousands of Arctic-bound shorebirds. The festival features shorebird viewing, field trips, lectures, and a birding marketplace 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 in which visitors participated in wildlife observation/photography. The diverse habitats found in the 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 peak spring migration (U.S. Fish and Wildlife Service, 2011).

Waterfowl hunting

Waterfowl hunting is another recreational use in the areas adjacent to the MSP Study Area. The Washington Department of Fish and Wildlife (WDFW) has management authority over all non-tribal waterfowl hunting within the state. All hunting requires a small game license with additional regulations applicable dependent 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 that 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 for details. 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). The Grays Harbor NWR does not allow hunting.

Table 2.6-1: 2015 Recreational duck hunting in Washington coastal counties. Source: WDFW, 2017.

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 Washington coastal counties. Source: WDFW, 2017.

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 southern coast of the MSP Study Area is razor clamming. The recreational harvesting, cleaning, cooking, eating, and canning of Razor Clams (*Silqua patula*) have been an important focus of family relationships and local culture in coastal communities for many generations. With between 275,000 and 460,000 seasonal digger trips resulting in the harvest of 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 30). Occasional long-term area closures of the Razor Clam fishery due to increases in levels of naturally occurring marine biotoxins (caused by harmful algal blooms) can significantly disrupt the fishery. These closures 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 Section 2.4: State and Tribal Fisheries.

While razor clamming is the more popular recreational activity, there is also a recreational hardshell clam fishery. Hardshell clams include Littleneck Clams (*Leukoma staminea*) and Butter Clams (*Saxidomus gigantea*). The National Park Service has done some population assessment of hardshell clams on beaches in Olympic National Park as shown in Map 30. 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 the lower density of the clams (Fradkin. S., NPS, personal communication, October 28, 2016). WDFW does also allow harvest of hardshell clams within the Willapa Bay estuary. Those stocks receive greater harvest pressure (Ayres, D., WDFW, personal communication, November 18, 2016).

Boating

As seen in Map 34, recreational vessels transit most of the MSP Study Area. The category of recreational vessels includes private vessels like sailboats, motorboats, and small independent fishing boats (only when they are transiting the area, but not when fishing). The data for this map was obtained through the Automatic Identification System (AIS) which is a tracking system used on ships and by vessel traffic services to identify and locate vessels by electronically exchanging data.[3] Recreational boaters on Washington's Pacific Coast 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 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).

[3] While AIS is required for larger vessels, it is not required for recreational private vessels. The map only includes data from vessels that choose to use AIS, therefore not all usage of the MSP Study Area by recreational vessels is represented in this map.

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. Several surfing spots are scattered along the Washington coast and surfers will travel great distances to reach quality waves. While surfers in the MSP Study Area are predominately from Washington, visitors from Oregon and British Columbia are also common. Surfers also come from as far away as Montana, California, the East Coast, and even Australia. 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 participants. Beach prospecting first began in 2008 on three beaches within the SCA. Interest from the prospecting community prompted a two year pilot program that was jointly evaluated by WDFW and the Washington State Parks and Recreation Commission (State 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 State 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 State Parks does not quantitatively track ocean prospecting, the state cannot provide current participation numbers. The most recent estimates are for May 2014 to July 2015, when WDFW required and issued about 260 individual HPAs for beach prospecting (Aaron, K., WDFW, personal communication, June 1, 2016).

Economic Impact of Recreation and Tourism

Recreation has always been a part of the economies of 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 coastal counties adjacent to the MSP Study Area (Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum) shows that tourism and recreation was the largest sector. It accounted for approximately 78% of employment and 50% 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. Point 97 & the Surfrider Foundation (2015) estimated that the total annual spending on coastal trips 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 trips to the coast in the MSP Study Area 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 coastal areas 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 throughout the state's economy, an estimated 9,309 jobs statewide and $413 million in labor income are supported directly and indirectly by recreation and tourism in the coastal area (Table 2.6-3).[4] Many communities adjacent to 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 Washington 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 associated 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, and in available 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 provide dining and lodging options.

[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 Section 2.3: Socio-economic Setting, and the Cascade Economics report.

National park and wildlife refuges

Olympic National Park (ONP) 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). ONP is the region's predominant recreation and tourism destination. It receives an estimated 3 million visitors annually, with about 759,000 to 783,000 estimated visitors each year to the three coastal park districts from 2011 to 2014. Park facilities include coastal public access points, trails, campgrounds, and wilderness campsites (Industrial Economics Inc., 2014).

Five National Wildlife Refuges (NWRs) managed by the U.S. Fish and Wildlife Service are located within the Study Area (Map 1). Flattery Rocks, Quillayute Needles, and Copalis NWRs are offshore. Public access to these islands is prohibited, although wildlife viewing from boats is allowed (Industrial Economics Inc., 2014). Grays Harbor and Willapa NWRs are on the mainland and open to visitors. Grays Harbor NWR is a main attraction in the Grays Harbor/Aberdeen area, where an 1,800-foot boardwalk provides access for viewing the hundreds of thousands of migrating shorebirds visiting the Refuge's muddy tidal flats. Willapa NWR 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 NWR in 2011, with associated spending totaling an estimated $1.8 million (Industrial Economics Inc., 2014).

State parks and public areas

The Washington State Parks and Recreation Commission manages several state parks, the 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. Over 9.2 million people visited Pacific Coast state parks, the SCA, and ocean beach approaches in 2013, associated 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 than in the northern half (Map 35). Coastal towns, state parks, the SCA, and broad sandy beaches are among the main reasons the public has more opportunities to access the beach in Grays Harbor and Pacific Counties. In Jefferson and Clallam Counties, remote locations, a rugged coastline, limited population centers, and tribal reservations limit the opportunity for convenient public access. Although, in some locations the tribes support and facilitate public tourism and recreation on their reservation lands. ONP also has access points, campgrounds, and wilderness campsites to facilitate 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 (Map 31) support public access to the water. 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[5]) and the 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 Indian Nation purchased the Ocean Shores Marina but it has been closed due to needed repairs and dredging. There is also 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 Nahcotta, Bay Center Marina, Tokeland Marina, Raymond Port Dock, and South Bend. Ilwaco and Chinook[6] 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 and camping expenses to be the greatest per-trip expenditure for coastal trips (averaging $25.96 spent per person on their last trip, including trips without lodging expenses). The average estimated total of annual expenditures for all visitors is approximately $481 million. 22% of that total is accounted for by lodging, or approximately $107 million annually (Point 97 & Surfrider Foundation, 2015).

Lodging highlights in Clallam County include the Hobuck Beach Resort owned by the Makah Tribe, the Quileute Oceanside Resort owned by the Quileute Tribe, and campgrounds and wilderness campsites in Olympic National Park. In Jefferson County, lodging within Olympic National Park includes the Kalaloch Lodge as well as a variety of campgrounds and wilderness campsites. In Grays Harbor County, the Quinault Indian 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, access limitations, and water quality issues. These issues are discussed below.

[5] Neah Bay is outside the MSP Study Area.
[6] Ilwaco and Chinook are outside the MSP Study Area.

Population Growth and Access

The specific recreational activities preferred by visitors to the coast have not changed substantially in recent history. A comparison of the results of the Surfrider Foundation recreation survey from 2014-2015 to a Washington State Recreation and Conservation Office report for 2002-2012 shows that of the top five recreational activities of beach going, sightseeing, camping, hiking, and photography, only the rate of beach going changed significantly, with an increase in 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 kiteboarding, showing demand for access.

Between 2015 and 2025, total population growth in the coastal counties is projected to average 9%, and statewide growth is predicted at 11% (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 water quality issues have impacted recreational users of ocean resources, and the potential exists for future effects as well. The razor clam fishery, which supports a highly popular recreational activity, has had frequent closures due to harmful algal blooms. Marine algal blooms have also killed birds and likely caused illness in other marine wildlife (Industrial Economics Inc., 2014).

Similar to the concerns highlighted in Section 2.4: State and Tribal Fisheries, 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.

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2.7 Marine Transportation, Navigation, and Infrastructure

Marine shipping, transportation, and 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 section summarizes the history, 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, and expanded with the introduction of European explorers focused on the region's natural resources. Trade continued to grow into the 18th and 19th centuries as competition for the northwest and its trade resources intensified. Washington eventually developed into 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 the 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, which 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 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. 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 in the states of Washington and Oregon.[1] The PNW Gateway accounted for $204 billion worth 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 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. These patterns dictate the traffic flow through the ports in Puget Sound, the Columbia River, and the Pacific Coast. Container traffic 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 to decline slightly, 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, global competition in the market is intense and the volume of corn available for export has decreased 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 for 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 have experienced generally slow growth in volume and are projected to continue to grow at a rate of 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 other liquids like chemicals and fertilizers being handled in much smaller volumes. The Port of Grays Harbor primarily handles 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 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 for LNG export at Ferndale.

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

The volume of liquid bulk transport by vessel has decreased over the past decade. This decrease was driven by a reduction in receipts of crude oil from Alaska as production there has decreased and been replaced by other sources, including crude oil coming to the PNW by rail from North Dakota. Waterborne movement of petroleum products is 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 neobulk[2] such as automobiles, lumber, heavy machinery, bundled metal, and scrap steel, and breakbulk[3] such as logs, forest products, and other project cargoes like wind turbines and heavy equipment parts. Most PNW automobile imports are handled in Columbia River ports, though some are handled in 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 due to growing demand from China, Japan, and Korea. Breakbulk exports of forest products like lumber, pulp, and paper have declined significantly, though they experienced 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 particularly significant impacts on vehicle imports. Since 2008, volumes have recovered and now exceed pre-recession levels. Volumes are expected to continue to grow slowly at an annual rate of 0.7 percent through 2035 (BST Associates, 2014).

Vessel traffic

Various types of vessels transit the MSP Study Area, including tank vessels and cargo vessels. Tank vessels carry bulk liquids like oil, methanol, biodiesel, and vegetable oil, and are either self-propelled tankers or tank barges that are propelled using a tug. Cargo vessels carry dry goods like grain and wood and include self-propelled cargo ships, cargo barges propelled using tugs, and RoRo (roll-on/roll-off) vessels 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 those used for fishing or recreation are described in other sections (see Section 2.4: State and Tribal Fisheries and Section 2.6: Recreation and Tourism).

Vessels are defined by their carrying capacity or deadweight tonnage (dwt), which describes the number of metric tons of cargo, stores, and bunker fuel that a vessel can transport. Tankers arriving to ports in the PNW range from 12,000-190,000 dwt. In Puget Sound, tankers carrying crude oil and petroleum 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 channels for the Columbia River and Grays Harbor do limit the size of vessel used in these areas. Crude oil and petroleum products are also handled by integrated tug-barges (ITB)[4] and articulated tug-barges (ATB).

[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 in recent years (Veentjer, J., personal communication, February 6, 2017).

The average size of vessels calling in PNW ports increased by 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 serve Alaska, Hawaii, and smaller international trade routes and range from in size from 1,000 to 5,000 TEU. Container vessels engaged in Transpacific trade have increased in size, with shipping line vessels increasing from 5,000 TEU to well over 10,000 TEU. The growing size of container ships for efficiency has resulted in a decrease in the number of container ship calls. This trend is expected to continue or level out in the future (BST Associates, 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 by 2013. This decline, averaging a 1.9 percent decrease per year, was due in part to increases in vessel sizes. Between 2013 and 2035 a forecast decline of 611 vessel calls averages out to -0.8 percent per year. This prediction is based on historical trends from Ecology reports on Vessel Entries and Transits and on 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.

Several maps show the density of different vessel types in the MSP Study Area: cargo vessel density (Map 36), passenger vessel density (Map 37), tanker vessel density (Map 38), and tug and tow vessel density (Map 39).

Navigation

The variety and density of vessels transiting the MSP Study Area necessitate several schemes designed to guide vessel paths through the area to avoid conflicts. These are discussed below, and shipping lanes, federal navigation channels, and navigation agreement lanes are highlighted in Map 40.

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 systems (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, 2016).

Vessel Traffic Service Puget Sound, maintained by the USCG, facilitates good order and predictability on the Salish Sea waterways by coordinating vessel movements through the collection, verification, organization, and dissemination of information. Vessels required to carry AIS in accordance with 33 CFR 164.46 can be tracked for informational purposes (USCG, personal communication, February 7, 2017). The USCG works cooperatively with the Canadian Coast Guard's Marine Communications and Traffic Services (MCTS) to manage vessel traffic in adjacent waters in order 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. The Exchange has the capability to monitor vessels out to about 50 miles off the coasts of Washington and Oregon (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, a southwestern approach, and a precautionary area.

Additional TSS are designated within the Strait of Juan de Fuca, for 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. Towboat lanes are designed to limit interactions between fishing gear and towing vessels that can destroy gear and foul the propellers and shafts of 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 OCNMS (Map 40). The IMO establishes ATBAs in defined areas where navigation is very hazardous or where they can contribute to avoiding casualties.

The ATBA within OCNMS recommends certain classes of transiting vessels 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 to all ships 400 gross tons and above that are solely in transit. Voluntary compliance rates are 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 the development of offshore energy systems (BST Associates, 2014). The Grays Harbor Navigation Channel is nearly 23 nautical miles (nm) long. It begins approximately 4 miles offshore and runs in an easterly direction, allowing access for deep-draft vessels to 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[5] recommends that where no other management measures 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 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 36, 37, 38, and 39, indicates 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.

[5] 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/.

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, including 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 the activity associated with this industry occurs outside the MSP Study Area and adjacent areas. The commercial companies in this sector are larger, but there are fewer of them, while recreational 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. It began by building oceangoing vessels for the Pacific commercial fishing fleet but now specializes in yacht and commercial construction. The company also has a shipyard in Port Angeles, WA and a yacht sales center in Fort Lauderdale, FL. Since the founding of the shipyard, 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, and the Port Angeles shipyard is a 100,000 square foot enclosed facility. A cabinet shop and upholstery shop also support 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 have an economic impact on the coastal counties adjacent to the MSP Study Area, but is challenging to isolate the impacts to just the coastal counties. This is because vessels transiting through the MSP Study Area are coming from and bound for a variety of locations, including Puget Sound or Columbia River ports, which are part of the total ocean economy in 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: 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 section 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).

Subsectors relevant to this section include maritime logistics and shipping, boat and ship building, repair, and maintenance, and maritime support services. Maritime logistics and shipping 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[6]	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

The NOAA Coastal Services Center[7] conducted a separate economic analysis using data from the Economics: National Ocean Watch (ENOW) database from 2005-2011 (NOAA Coastal Services Center, 2014). 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 on Pacific coastal counties compared to its impact statewide is displayed in Table 2.7-2.

[6] Included in this subsector are more than 11,000 civilian jobs at the Puget Sound Naval Shipyards in Bremerton.
[7] In 2014, the NOAA Coastal Services Center merged with NOAA's Office of Ocean and Coastal Resource Management to form NOAA's Office for Coastal Management.

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

Marine Transportation	Pacific Coastal Counties[8]	Statewide
Establishments	6	409
Employment	63	19,105
Wages (thousands of dollars)	4,523	1,279,000
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 on 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 total economic impact based on five commodities at 2013 cargo levels: wood chips, grain, automobiles, logs, and liquid bulk. Table 2.7-3 shows 574 direct jobs and $143.5 million in direct business revenue generated by these five commodities through the port. Of the 574 direct jobs, 94 percent were held by Grays Harbor residents (Martin Associates, 2014).

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 the payment of salaries and wages, purchases 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).

[8] These numbers are reported for the five Pacific coastal 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.

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

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, from ports on the West Coast, and even from the East and Gulf Coasts. Shifts in 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, storage, and vessel and gear maintenance. An overview of ports and marinas is provided here, with further detail on fishing-related functions available in the State and Tribal Fisheries section and dredging requirements in the Dredging and Dredge Disposal section.

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 (adjacent to the MSP Study Area), 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 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, Baker, Waters, Wegge, & Wellman, 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 the 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 at that time, and generally does so every two years. The west end of the marina has facilities that the tribe leases to High Tide Seafoods including a high dock with a lift, an ice machine, and space for a fish processing plant in La Push. The marina serves both 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 and 1990s, the Port worked to diversify its business (Ott, 2010). The Port did this in part by undergoing a dredging project to accommodate oceangoing vessels that continue to increase in size. The Port also utilized an agreement with a shortline railroad to maintain a connection with two Class 1 Railroads, which allowed for the development of a bulk handling facility and automobile export operation (R. Lewis, personal communication, Jan. 13, 2017). 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 ships goods including automobiles, biodiesel, other liquid, dry bulk, and overhigh/overwide (OHOW)[9] products.

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-foot-long berth that can handle two vessels and serves as the primary Ro/Ro and breakbulk cargo terminal. Terminal 3 is a deepwater 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 to 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 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).

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

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 aboveground 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 for 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. An additional 700 feet of floating dock is available for moorage (Port of Willapa Harbor, n.d.). The Bay Center Marina provides moorage for oyster barges and fishing vessels, with capacity for 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.).

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.).

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, adjacent to the MSP Study Area. 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, adjacent to the MSP Study Area. 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, a boat hoist, and a fueling facility (Taylor et al., 2015).

Emergency Response

United States Coast Guard

The USCG 13th District is made up of Washington, Oregon, Idaho, and Montana and the entire coast of the Pacific Northwest, including the MSP Study Area. The Study Area is served by operations based in Sector Puget Sound and Sector Columbia River. Daily operations include conducting search and rescue and patrolling the coast to enforce safety and fishing regulations (United States Coast Guard, 2015).

The USCG Station Grays Harbor has the Coast Guard's first on-water response responsibility over the area ranging from the 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 Pacific Northwest coast with 50 crewmembers. The station has five search and rescue boats and provides search and rescue for 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 crewmembers respond to 300-400 calls for assistance each year (United States Coast Guard, 2016). 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 than 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, 2016).

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 (U.S. Coast Guard, 2004).

USCG Station Neah Bay is located within the Makah Indian Reservation, adjacent to the MSP Study Area. Station Neah Bay has two lifeboats to respond to emergencies from Cape Alava to the northern extent of the MSP Study Area (U.S. Coast Guard, 2003).

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

[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

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 experiencing maneuvering issues (e.g. propulsion and steering problems) or vessels that are directed by the U.S. or Canadian Coast Guard to obtain towing or escort assistance (National Oceanic and Atmospheric Administration, 2016). More than 90% of the assistance provided by the ERTV has been escorting, often as required by the U.S. Coast Guard (J. Veentjer, personal communication, February 6, 2017).

The ERTV 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. 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 (City of Hoquiam & Washington State Department of Ecology, 2016).

Since 1999, the ERTV has been deployed to either stand by for 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 fishing and fish processing vessels, fully laden oil and chemical tank ships, and tugs with tank barges in tow. (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] 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 on individual Pacific coast ports and activities based on projections for the larger area. These projections do not include potential increases in cargo and vessel traffic that could occur if projects proposed for areas impacting the MSP Study Area move forward.

Changes in world trade patterns may affect trade flow 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

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).

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. This trend is expected to continue and then stabilize with a forecasted 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 on the West, East, and Gulf Coasts. The Port has previously been able to diversify to maintain a competitive edge as products being shipped have shifted away from forest products and towards other cargo like auto exports. 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. 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 as well as in Vancouver, British Columbia. Alaskan crude oil, transported by tankers and pipelines, has been decreasing and is expected to continue to decline. However, an 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. This 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.

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 vessels transiting through the MSP study area and increase the volume of crude oil carried through the area.[12]

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 the

[12] As ruled by the Washington State Supreme Court in *Quinault Indian Nation, et al v. Imperium Terminal Svcs., et al.* No. 92552-6, the City of Hoquiam's shoreline permit for these crude oil export projects, if issued, must demonstrate the projects meet the permit criteria in the Ocean Resources Management Act (RCW 43.143.030(2)) and any associated regulations. See Chapter 4: MSP Management Framework for additional information.

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 vessel calls annually 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.).

Additional projects involving crude oil have been proposed along the Washington side of the Columbia River. One project currently in the permitting stages is Vancouver Energy, proposed by Tesoro-Savage. The project would include a rail unloading facility, storage tanks, and a vessel loading area. It would bring up to 360,000 barrels of crude oil by rail to the Port of Vancouver daily, where it would then be loaded onto vessels for transport to refineries in Alaska, Hawaii, California, and Washington. Under proposed typical operations there would be an additional 365 vessel calls per year to load and transport the crude oil (Energy Facility Site Evaluation Council, 2015).

Oil spill preparedness and response

Vessels transiting the MSP Study Area bring the potential for oil spills, an ongoing challenge of managing marine transportation. Oil spill risk can be defined as the probability that a particular type of spill incident is likely to occur and is influenced by the spill source, volume, oil type, season, and location (Environmental Research Consulting, 2009). Oil spill prevention, preparedness, and response activities address this risk but cannot completely eliminate it.

Different types of oil present different risks when spilled. Bakken crude and other shale oils can most closely be compared with light oils like diesel and have high evaporation rates. However, they are also highly flammable and volatile. Diluted bitumen from “oil sands” has been transported in Washington for decades and may sink when spilled in water depending on its formulation and the density of the water. A study conducted for the State found that the environmental risks from oil spills are highest for heavy fuels, followed by crude oil, and lower for light oils and gasoline. This trend is related to the higher persistence of heavier oils and the associated increased threats to organisms and habitats (Washington State Department of Ecology et al., 2015)

There are a number of state and federal laws and regulations that address the potential for oil spills on or near the water and associated preparedness and response planning and actions. The USCG is the federal agency responsible for oil spill prevention and preparedness and for response actions relating to vessels or vessel loading facilities.[13] The Washington State Department of Ecology (Ecology) has state responsibility for preventing and planning for oil spills and response actions in state waters for all sources of oil discharge. These agencies provide oversight and ensure that the responsible party initiates a rapid and satisfactory response.

Vessels transporting oil have a variety of required measures that contribute to the prevention of oil spills. These include construction design (double bottoms and sides), mechanical measures (oil discharge monitoring systems and emergency shutdown devices), and

[13] The EPA is the federal agency responsible for oil spill prevention and preparedness and for response actions relating to rail unloading facilities and storage tanks.

navigational equipment (depth sounders and electronic position fixing devices to verify position and prevent collisions or groundings). Onsite storage and handling facilities at the terminals 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 using 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 that 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 that establishes roles and responsibilities, identifies resources, and identify response procedures for oil spills or threat thereof. This framework includes the National Contingency Plan, Northwest Area Contingency Plan, local response plans, facility response plans, vessel response plans, and transportation regulations. The Northwest Area Contingency Plan[14] 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). GRPs relevant to the MSP Study Area include those for the Strait of Juan de Fuca, the Outer Coast, Grays Harbor, Willapa Bay, and the Lower Columbia River.

[14] 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 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

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2.8 Military Uses

There is an extensive and ongoing history of military presence within Washington State and the MSP Study Area. Ocean uses primarily include United States Coast Guard navigation, search and rescue, vessel safety, and coastal defense operations, and activities within the United States Department of the Navy training and testing ranges.

Summary of History and Current Use

United States Department of the Navy

The United States Department of the Navy has had an active presence in Washington since the mid-nineteenth century. Active range complexes within the Navy's Northwest Training and Testing Area include parts of Puget Sound, Alaska, and offshore Pacific Ocean waters. 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 in the eastern North Pacific Ocean which overlap with the MSP Study Area, including both air and water space areas. 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 41).

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 continue southward parallel to the coasts of Washington, Oregon, and Northern California. The NWTRC includes Special Use Airspace (SUA), which comprises Warning Area 237 (W-237) off of Washington (Map 41). W-237 incudes sea surface and underwater areas, and extends into airspace to varying degrees. Various sub-areas have ceilings of 27,000 ft, 50,000 ft, or unlimited height depending on the sub-area. The Olympic Military Operation Areas (MOAs) overlay land (the Olympic Peninsula) and waters out to 3 nm from the coast. The Navy's Offshore Area, which encompasses but is larger than the Study Area, includes sea and undersea space with a total of 121,000 nm^2 of surface area. The sea space is used for all levels of Navy training and for U.S. submarine transit lanes (United States Department of the Navy, 2015).

The Naval Undersea Warfare Center Division Keyport Range Complex includes the Quinault Range Site within the boundaries of the Offshore Area. The Quinault Range Site is located off the coast of Jefferson and Grays Harbor Counties with the same boundaries as W-237A and includes 1 mile of shoreline at Pacific Beach, WA. Surf zone activities would be conducted from an area on the shore and seaward (United States Department of the Navy, 2015).

The Navy tests ships, aircraft, weapons, combat systems, and sensors and related equipment, and conducts scientific research activities to achieve and maintain military readiness. The Navy uses the Offshore Area (including the MSP Study Area) for training activities 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 testing and training activities. Specific examples of Navy activities include flight formation practice, submarine mine exercises, target practice, tracking exercises, and torpedo testing (United States Department of the Navy, 2015).

The Navy must train and test to meet the requirements of Title 10 of the U.S. Code to maintain, train, and equip combat- ready naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas. In addition to the types of training and testing activities that could occur in the Offshore Area as identified in Appendix A of the Final Northwest Training and Testing Environmental Impact Statement/Overseas Environmental Impact Statement of October 2015, routine surface and submarine vessel transits, ocean observing systems, research projects and seafloor cable systems can occur within the MSP Study Area.

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 1850s, 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, 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 operations, 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 Coast Guard serves the dangerous waters of the Washington Pacific coast. The stormy and foggy conditions often encountered in the MSP Study Area necessitated the development of several lighthouses and lifesaving stations to protect lives and respond to emergencies. Today, the 13th District operates within the MSP Study Area based out of units in Ilwaco (Station Cape Disappointment), Westport (Station Grays Harbor), La Push (Station Quillayute River), and Neah Bay[1] (Station Neah Bay) (Map 41) (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.

[1] Neah Bay is outside the MSP Study Area, but Coast Guard vessels out of Station Neah Bay operate within the MSP Study Area.

Related Infrastructure

The Navy's use of the MSP Study Area consists mostly of training and testing activities, and does not include pier-side infrastructure (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 (Map 41). 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).

Unexploded ordnance are explosive weapons that did not explode when they were employed and still pose a risk of detonation. They are mapped in the MSP Study Area based on NOAA navigation charts (Map 41). This data is not considered a complete representation of all unexploded ordnance on the seafloor, nor are locations exact.

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 (United States Department of the Navy, 2015). At the time of writing, the Navy has proposed special operations training to conduct small unit, intermediate and advanced land and cold-water maritime training for Navy special operations personnel. The training will take place in the coastal and selected nearshore lands of western Washington State, with the permission of willing property owners. This proposed training would involve personnel movements with the intent to teach trainees the skills needed to avoid detection and maintain an uncompromised presence during and after training. The proposed training locations in the MSP Study Area include the Westhaven, Westport Light, Twin Harbors, Leadbetter Point, Pacific Pines, and Cape Disappointment State Parks on the southern coast.

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2.9 Research and Monitoring Activities

The marine waters off Washington's Pacific coast host a wide variety of research and monitoring activities conducted by numerous institutions and government agencies, including many focused on collecting baseline data to understand oceanographic conditions. Other research includes surveys of fisheries and other marine animal populations, 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 focus of a variety of oceanographic, geologic, and marine biological 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, the Northwest Fisheries Science Center, the National Centers for Coastal Ocean Science, the National Data Buoy Center, tribal governments, Washington state agencies, and the Olympic Coast National Marine Sanctuary.

Other federal agencies that perform research also include the United States Fish and Wildlife Service, the United States Geological Survey, and Olympic National Park. Many of these institutions work collaboratively with each other and other 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 MSP Study Area is the collection of baseline data to understand oceanographic conditions, marine habitats and populations, and marine hazards. Information collected includes data describing 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.

Research equipment includes moorings, anchored hydrophones, vessels outfitted with sampling and trawling gear, shore-based instrumentation, and in-water gliders equipped with oceanographic sensors. Research vessels owned by state universities are based in Seattle or in Newport, Oregon. NOAA's research ships serve the entire West Coast from California to Alaska and are based in Newport, Oregon. OCNMS utilizes a research vessel, the *R/V Tatoosh*, which operates out of La Push during the field season from April to October. State agencies operate small (<30 ft) 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 shoreside stations (Map 42). These are generally equipped with sensors to measure oceanographic conditions, such as water temperature, carbon dioxide, light, wave height, and wind. Oceanographic buoys, both seasonal and year-round, include NANOOS' Chá bă buoy and the accompanying NEMO sub-surface profiler off of La Push, NOAA National Data Buoy Center'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 part of the Ocean Observatories Initiative's Endurance Array, recently deployed offshore of Grays Harbor. The array consists of three buoys along an east-west transect (Woods Hole Oceanographic Institution, 2011). The Navy funds long-term passive acoustic monitoring conducted using temporary devices that are deployed on the bottom to record high frequency acoustics (Department of the Navy, 2015).

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 MSP Study Area will likely remain an important region for scientific research and resource management surveys, particularly for activities which provide information on key processes and issues such as fisheries populations and practices, ocean circulation, climate change, water temperature, ocean acidification, hypoxia, and harmful algal blooms.

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2.10 Potential New and Expanded Uses

2.10.1 Marine Renewable Energy

Marine renewable energy includes the conversion of potential energy from waves, tidal currents, and offshore wind[1] 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 diversify their energy portfolios 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 acquiring 3% of total load from renewable energy sources by January, 2012, 9% by January 2016, and 15% by January 2020 (RCW 19.285).

Types of renewable energy that qualify under the Renewable Energy Portfolio Standard include marine renewable energy (e.g., 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 Marine Spatial Plan (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 that have minimal potential for conflicts with other existing uses or sensitive environments (RCW 43.372.040(6)(c)). Development of a framework for coordinating local and state agency review of proposed energy projects is also required (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 energy. This includes information about 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 provide key information about marine renewable energy.

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[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, 2014).

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

Summary of History and Current Use

History in the United States and Abroad

Several countries are currently promoting the use of marine renewable energy. Europe is currently the leader in offshore wind development and installed capacity, with the United Kingdom, Denmark, Belgium, and Germany leading the market (Navigant Consulting, Inc., 2014). The United Kingdom is also leading the market for testing sites for wave and tidal energy devices (Pacific Northwest National Laboratory, 2017). As of 2015, the global offshore wind energy capacity of installed devices 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 researchers at Department of Energy facilities including the National Renewable Energy Laboratory (NREL), the Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratory. Research is also ongoing at other institutions such as the Northwest National Marine Renewable Energy Center (NNMREC), the 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 marine wind farm in the United States, Block Island Wind Farm, began operations in December 2016 off the coast of Rhode Island. The Bureau of Ocean Energy Management (BOEM), the federal agency responsible for issuing leases for offshore energy in federal waters, has issued 12 commercial wind energy leases on the outer continental shelf (OCS) as of March 2017 (Bureau of Ocean Energy Management, 2017). BOEM 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 coordination between federal, state, and local governments and to engage stakeholders (Navigant Consulting, Inc., 2014).

At the time of writing, no marine renewable projects have moved beyond planning or permitting on the West Coast. In Oregon, Principle Power proposed an offshore wind project to be located about 18 miles offshore from Coos Bay. The WindFloat Pacific Project was planned to consist of up to five deep-water turbines in approximately 350 meters (1,150 feet) of water depth with an estimated project capacity of up to 30 MW. (Principle Power, Inc., 2013). Principle Power withdrew its lease request in 2016 and BOEM is no longer processing the application. In 2016 in California, BOEM and the state initiated the competitive planning and leasing process for possible future offshore wind development in response to an unsolicited request for a commercial lease and a subsequent notification of competitive interest (Bureau of Ocean Energy Management, n.d.).

The majority of offshore renewable energy projects in the United States are under development on the East Coast. At the time of writing, BOEM has issued active commercial leases in New York, Massachusetts, New Jersey, Delaware, Maryland, Virginia, and North Carolina. There are also lease requests under consideration in New York and Massachusetts. In Virginia, BOEM has three cooperative research agreements with the State. In South Carolina, BOEM has published a Call for Information and Nominations (Call) to gauge the interest of the offshore wind industry in acquiring leases for four offshore areas. Additionally, BOEM has issued a Call to seek nominations from companies in Hawaii. The status of BOEM's leasing activities and the progress of industry projects is constantly evolving (Bureau of Ocean Energy Management, n.d.). Timely information and additional details can be found on BOEM's website at: https://www.boem.gov/Renewable-Energy-State-Activities/.

The U.S. also has a small number of wave and tidal current energy device testing facilities, sites, and pilot projects. These enable feasibility testing of technology as well as the study of potential environmental effects (Augustine et al., 2012). The Pacific Marine Energy Center (PMEC) is a collection of NNMREC marine energy testing facilities. NNMREC is a a partnership between Oregon State University and the University of Washington. NNMREC has been working with partners on establishing a grid-connected, open-water wave energy test site off Newport South Energy Site (PMEC-SETS) in which is in the advanced stages of planning, and additional capacity for testing sub-scale current turbines is being developed (Oregon State University, 2015).In addition to these facilities, the U.S. Department of Energy and U.S. Department of Defense have established the Wave Energy Test Site (WETS) on Oahu, Hawaii 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).

History in Washington

There have been several marine renewable energy proposals in the State of Washington 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 actively 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 ft and would have been 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. They collected information describing the physical environment and benthic habitat, as well as 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). They surrendered the FERC license in December 2015.

The University of Washington is a partner in NNMREC for researching and testing tidal current devices. The University has supported testing for two intermediate-scale temporary wave converters, one in Puget Sound and one in Lake Washington, both of which are 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 from a mobile platform (B. Polagye, personal communication, June 7th, 2015). PNNL's Marine Laboratory in Sequim is testing environmental monitoring technologies to potentially be used 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, waves, and tidal currents. The following sections briefly describe the technologies associated with 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 the land-based transportation logistics which restrict onshore wind turbine size (Navigant Consulting, Inc., 2013b, 2014). Planned offshore wind projects in the U.S. currently have an average turbine capacity of about 5 MW, and range from 3 to 8 MW (Navigant Consulting, Inc., 2014). For example, the turbines for the now defunct WindFloat Pacific project were planned to have 6 MW capacity with rotor diameters up to about 500 feet (Principle Power, Inc., 2013). Some manufacturers are pursuing turbine designs in the 10 to 15 MW range (Navigant Consulting, Inc., 2014).

Globally, there is a trend toward selecting sites in deeper water at greater distances from shore. There are associated increased costs due to more complex installation, longer export cables with related line losses, and increased operation and maintenance costs for vessels (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). This is greater than that for terrestrial wind, with an average net capacity factor of about 32% in the Columbia Basin (Northwest Power and Conservation Council, 2016).

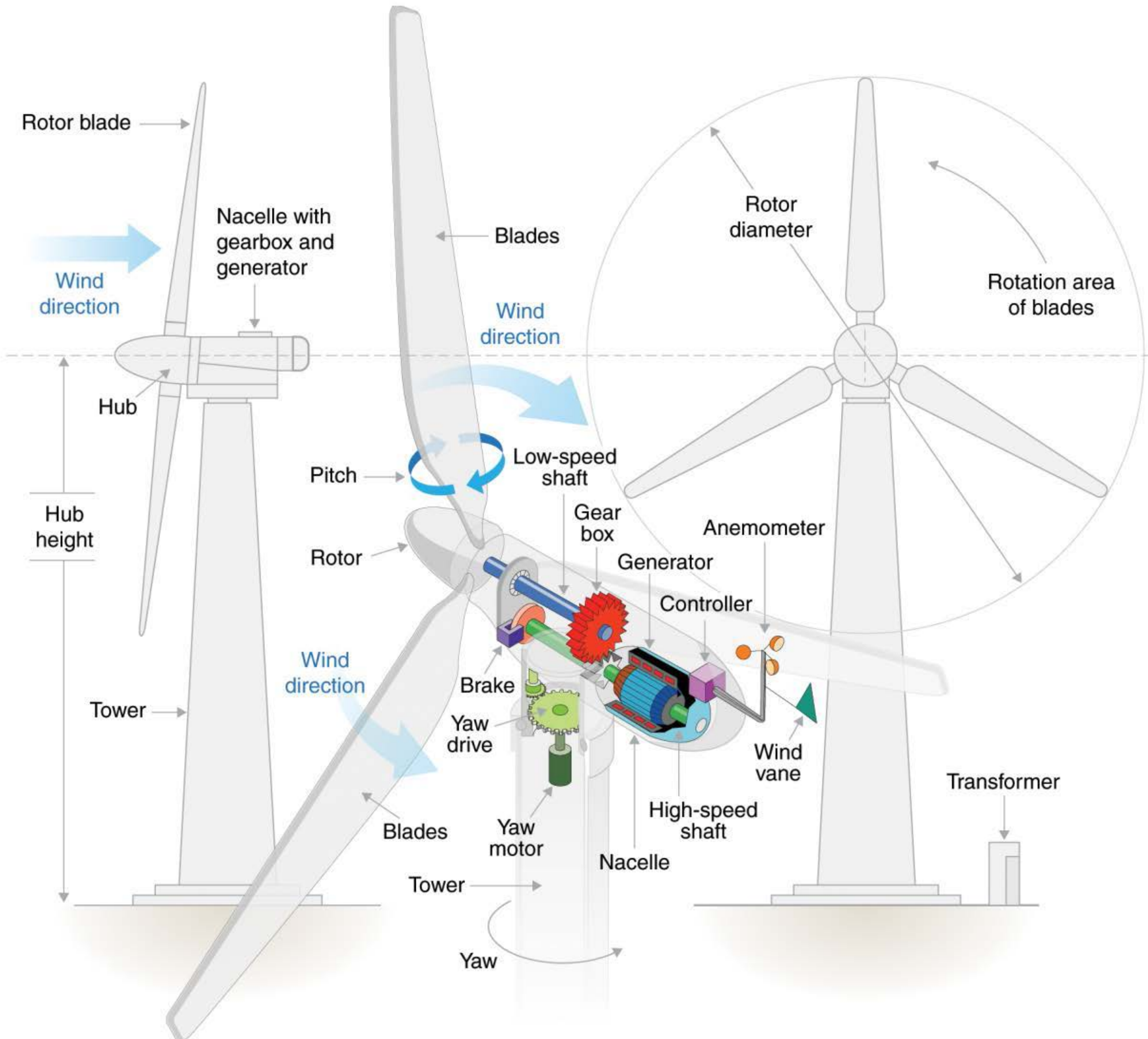

Figure 2.10.1-1. Components of a wind turbine. Source: Augustine (2012).

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. Currently, the most commonly used foundation in 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 about 30 meters (100 feet) or less in depth (Musial & Ram, 2010; Sotta, 2012). Technologies in the development and demonstration stages for transitional water depths (30 to 60 meters; or 100 to 200 feet) include tripod, jacket, multi-pile (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 legs, and spar buoys (Musial & Ram, 2010) (Figure 2.10.1-2). Anchor and mooring systems will vary by floating project. For example, the Coos Bay WindFloat project was designed to use a floating semi-submersible design. The project planned 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.

Off the West Coast of the United States, the seafloor drops off much more quickly than on the East Coast. This results in much deeper waters closer to shore, and affects the type of infrastructure required. The National Renewable Energy Laboratory researched the offshore wind resource available throughout the United States (Schwartz et al., 2010). In Washington, there is significant wind resource available from the Pacific coast out to 50 nm. Within state waters (0-3 nm from shore), the wind resource is mostly found in water depths of 0-30 m. However, in some areas the wind resource is available in areas with water depths over 60 m. Within 3-12 nm from shore, the areas with available wind resource are mostly associated with water depths greater than 30 m. At distances of 12-50 nm from shore, the majority of the wind resource is found at water depths greater than 60 m (Schwartz et al., 2010).

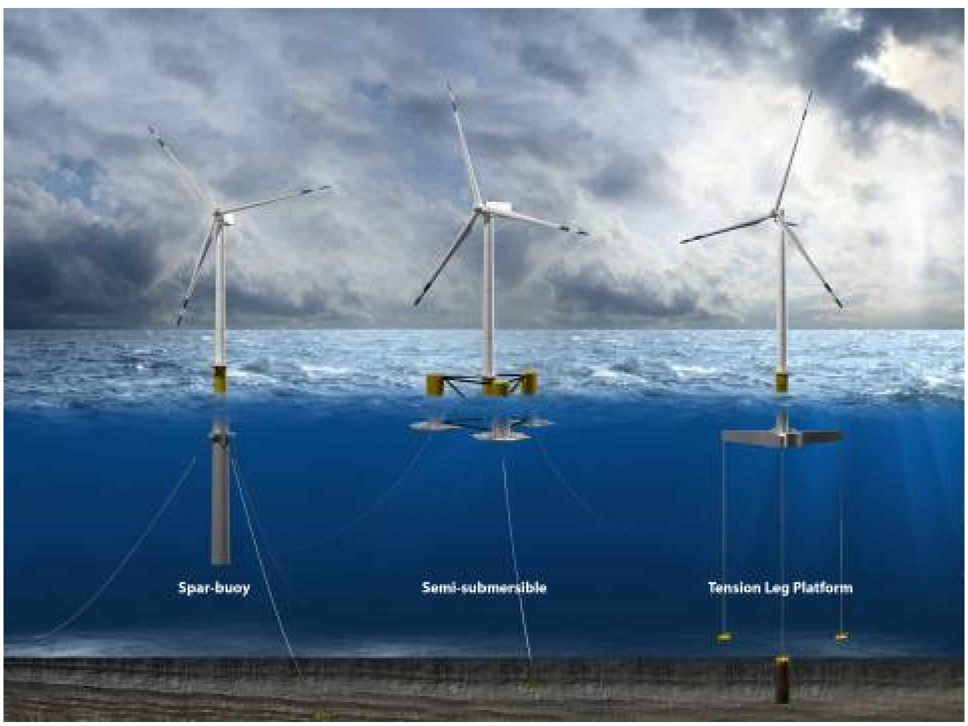

Figure 2.10.1-2. Floating offshore wind designs. Source: Department of Energy.

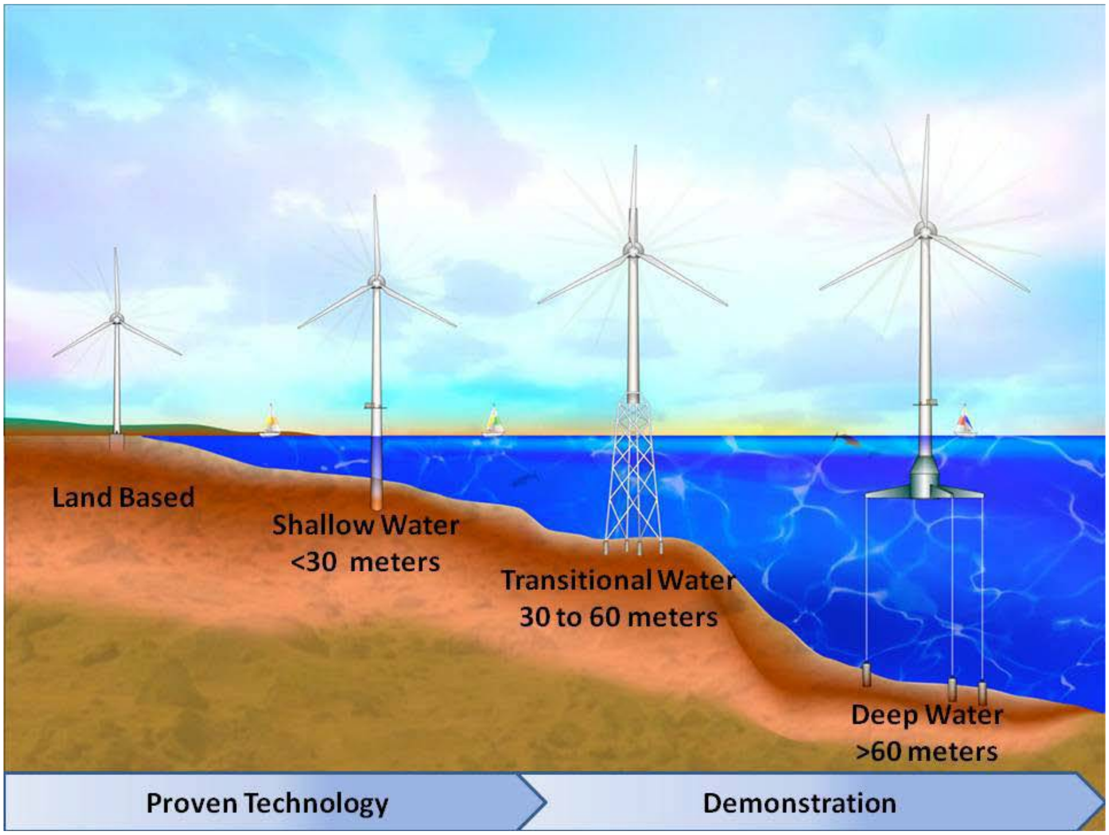

Figure 2.10.1-3. Diagram displaying examples of differences in offshore wind technology types by depth. Source: Musial and Ram (2010).

Wave Energy

Wave energy is categorized as a type of marine hydrokinetic energy (MHK) technology. MHK technologies convert energy from a moving fluid, such as 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 types of technology for wave energy (2012). Figure 2.10.1-4 provides a visual summary of the following types of technology:

- **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 through either 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 low-head hydropower facilities 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 wave energy into electrical energy.

The **M3 nearshore wave energy device** is an additional wave device type described in the Pacific Northwest National Laboratory (PNNL) energy suitability analysis for Washington. It is a pressure device that sits below the ocean’s 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. Some devices are designed for the coastline and shallow waters (<10 meters or 32 feet), and others are designed for mid-water depths and water depths of up to 125 meters (410 feet).

Mooring technology and configuration will vary by project and technology type. They are 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).

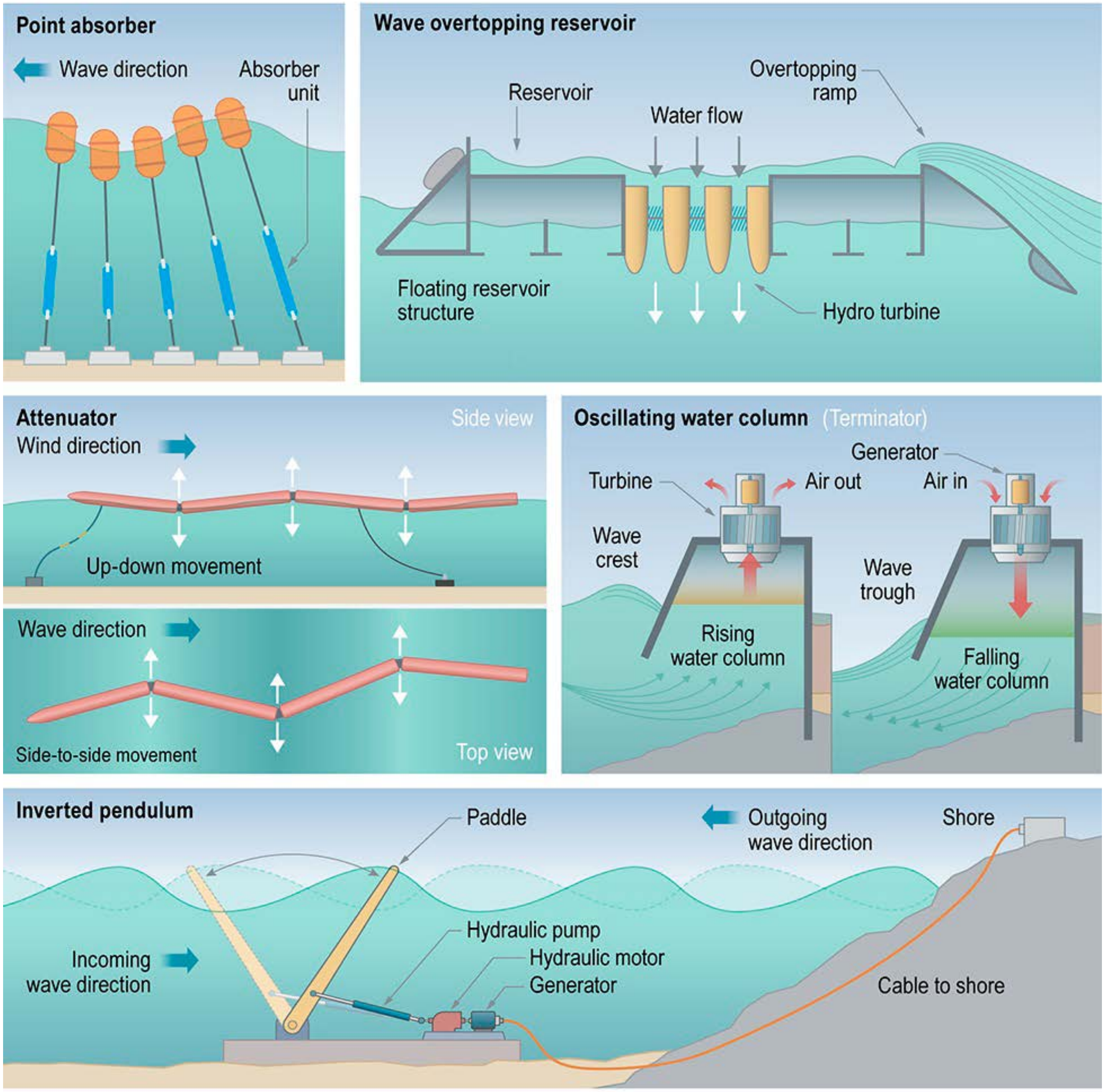

Figure 2.10.1-4. Wave energy technology types. Source: Augustine (2012).

Tidal Current Energy

Tidal current energy is also categorized as a type of MHK technology, because it converts 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 includes several different types and configurations of technology (Augustine et al., 2012). Examples of tidal current technologies are shown in Figure 2.10.1-5. Tidal turbines

[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.

require relatively strong currents to produce significant amounts of electricity. The depth of turbine deployment is dependent on the type of technology 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. First-generation deployments have generally been outside of shipping channels (Polagye, Van Cleve, Copping, & Kirkendall, 2011).

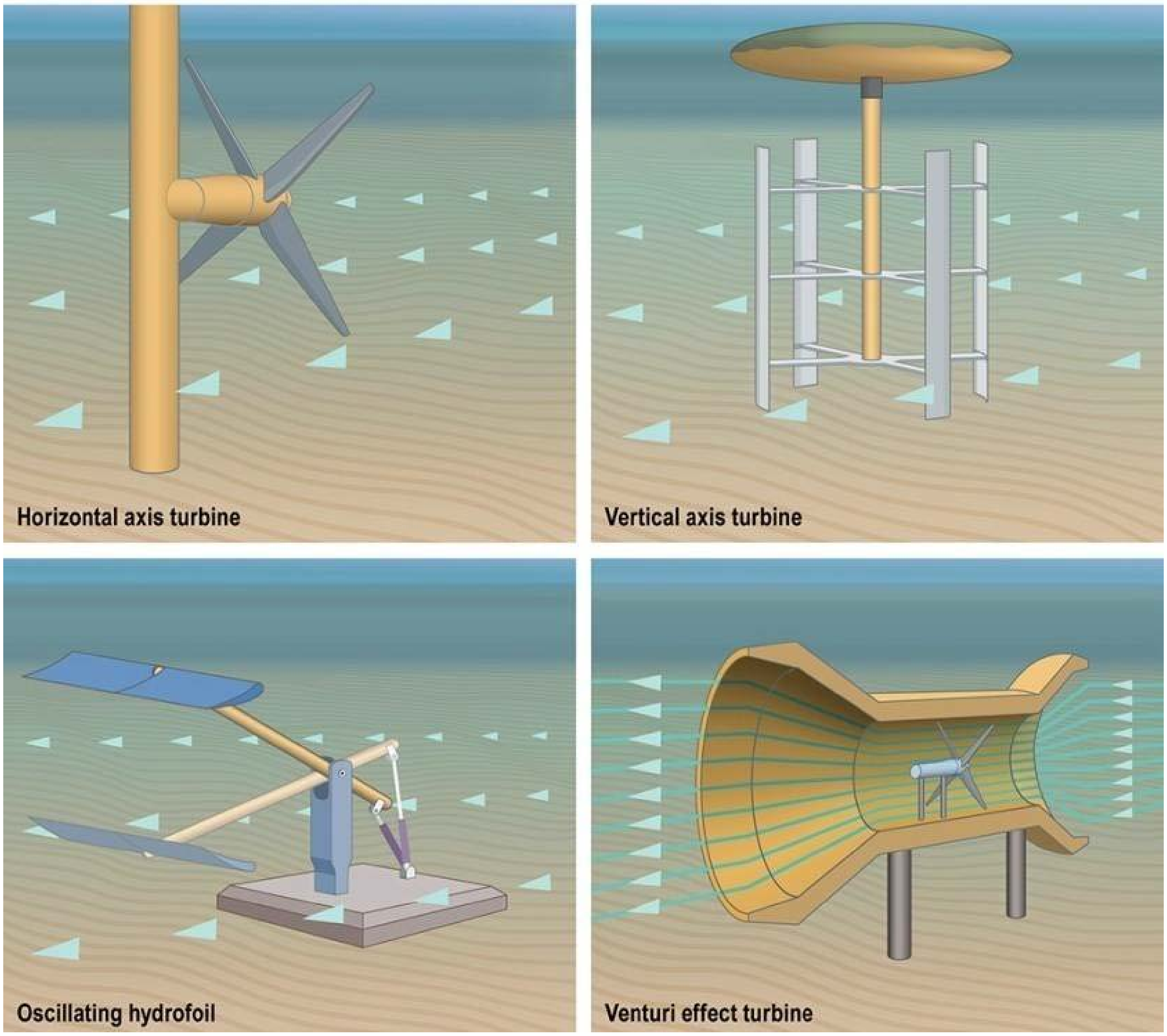

Figure 2.10.1-5. Primary technology types for tidal current energy devices. Source: Augustine (2012).

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 manufacturing facilities (Musial & Ram, 2010).

Energy Transmission Infrastructure

The exact technology requirements for energy transmission infrastructure 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 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 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 ongoing (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 cross under sensitive nearshore areas and make landfall at an onshore substation (Polagye et al., 2011).

Another important element of 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 feasibly be sited (Van Cleve et al., 2013). These substations must also be capable of accepting additional electricity loads for distribution (electricity "on-ramps"). 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 associated with overcoming transmission capacity and efficiency constraints on bringing the energy to shore and integrating it into the grid (Navigant Consulting, Inc., 2014). Some developers are exploring the option of providing site-based energy with limited or no connection to the grid, for use in remote coastal communities or 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). A company in Scotland is also testing wave energy to provide electricity to finfish farms (Mercador Media, 2014). The former Makah Bay Offshore Wave Energy Pilot Project was 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 the construction, operation, and decommissioning of devices. Distances to service ports, deepwater ports with sufficient overhead clearance (needed for offshore wind devices), and helicopter operations (also for offshore wind) were identified by PNNL to be contributing attributes to the suitability of a location for marine renewable energy projects (Van Cleve et al., 2013). Specialized vessels will also likely be required for installation, operation, maintenance, and decommissioning, particularly for shallow-water offshore wind. 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 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, or fossil fuels. Fossil fuels 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 such as oil, natural, gas, or uranium. Offshore wind and wave energy are forms of solar energy, and tidal energy is a result of the 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. Utilities in Washington purchase electricity from a variety of sources in a multi-state, regional bulk power system (Washington State Department of Commerce, 2016). In 2014, about 68% of the total annual electricity delivered in Washington was from renewable sources. Hydropower (dams) accounted for 65% of total electricity consumed, land-based wind accounted for 3%, and other renewable energy sources accounted for less than 1% (Washington State Department of Commerce, 2016). After hydropower, coal (15%) and natural gas (12%) were the next largest sources of electricity (Washington State Department of Commerce, 2016). 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

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 could include both 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, and infrastructure update requirements. 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 conflicts and other factors (see section on 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 cost-benefit analysis for jobs, to provide a more accurate estimation of the type of economic effect a project may have on the local community and the state.

Washington benefitted economically from the former WindFloat Pacific project in Oregonof m, as Washington-based companies participated in the development, permitting, and siting of the project. Had the project been completed, Principle Power estimated that it would have attracted more than $200 million in federal and private investment into the Northwest economy (Industrial Economics, Inc., 2014). In addition, some Washington-based companies are or will be suppliers of components for floating offshore wind installations (A. Weinstein, personal communication, May 15th, 2015). There is also the potential for benefits to ports, as offshore operations will need shoreside support. Proximity to a deepwater port (such as Grays Harbor) will also be important for constructing and transporting wind turbines. The necessary shoreside support facilities do not currently exist, so this would require investment (Industrial Economics, Inc., 2014).

Diverse energy portfolio and increased energy security

Another commonly-cited benefit of marine renewable energy development is the diversification of the U.S. 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 renewable energy near coastal areas with high energy demand (Musial & Ram, 2010). Transmission infrastructure updates would be required, and there is active interest on the Atlantic coast in developing 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. Therefore, 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 in 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. 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) also 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. This 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 (Washington Coast Marine Advisory Council, 2015).

Marine renewable energy is also potentially compatible with other potential future uses of the ocean, such as co-location of offshore wind with offshore shellfish (Buck et al., 2008; Buck, Ebeling, & Michler-Cieluch, 2010) and seaweed aquaculture (Buck et al., 2008). The foundation structures for offshore wind may provide an opportunity for anchoring, protecting, and accessing shellfish or seaweed cultured in the ocean environment (Buck et al., 2008). Seaweed cultivated through aquaculture could then potentially be processed and used for biofuels (Renewable Energy Magazine, 2012). 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 of marine renewable energy on the marine environment on are a key concern to many scientists, regulators, 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 on 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. However, 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, most of which are pilot- and small-scale projects, 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. They 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 for marine renewable energy in general. Any predicted effects specific to a device are also discussed. 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 ocean and coastal environments. 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 that generated from pile driving, is the source of noise most commonly cited within the literature as having the largest potential for negative impacts to marine animals. Pile driving creates intense, pulsed noise. It 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 projects in relatively shallow water (Bergstrom et al., 2014). It may also possibly be used for tidal current devices, 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) summarize mitigation measures for construction activities including avoiding important recruitment areas for marine mammals and fish, and timing construction activities to occur 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).

Operational sources of noise (e.g. machine operation, strum, wave and wind interactions) 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 increase susceptibility to predation by killer whales. Fish may experience behavior changes or losses 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 sited 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).

Boehlert et al. (2008) presented several mitigation methods for reducing the effect of operational noise from wave energy devices. These include varying the array design to reduce synchronous sound (additive noise), using thicker mooring cables to reduce the frequency of cable strum, using 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, they could even be attracted to the devices (Boehlert et al., 2008). Animals unable to hear the device arrays, animals that become confused by 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 that it is unlikely that individual devices or small arrays will have large-scale effects on animal behavior or survival. 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 (those that are looser and have slack in the mooring line) having the greatest relative risk and taut moorings the lowest risk (Benjamins et al., 2014).

Benjamins et al. (2014) also concluded that the great 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 the biological, behavioral, and migratory patterns of whales. The study described how whales become entangled in slack fishing lines when 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 by a cable include an electric field, an induced magnetic field, and an 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 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 to 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 by in-water generating devices themselves, as well as by transformer substations (Boehlert et al., 2008; Polagye et al., 2011).

Scientists and regulators have identified concerns about EMF effects on marine animals, particularly 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 on 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).

A study was performed to assess changes in the behavior and paths of bony fishes and sharks before and after the activation of the Trans Bay Cable (TBC), a transmission line buried through the San Francisco Bay. The results indicate that Chinook Salmon smolts may be attracted to the cable after activation, but their successful migration through the bay was not impeded. Green Sturgeon migrations were impacted, with outbound migrations having significantly longer transit times and inbound migrations having significantly shorter transit times. Overall, the proportion of successful migrations was not strongly impacted after the cable activation (Bureau of Ocean Energy Management, 2016).

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 pose a risk of striking marine animals with their rotating turbine blades or other moving parts. Stakeholders and regulators are concerned with this potential for marine animal strikes. Animals 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). Wind turbines present a risk of strike to birds and bats (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 models of mammal 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. 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 confirmed no observed instances of marine mammals, fish, diving seabirds, or other marine animals 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 assessed the potential and severity of an injury to a killer whale from a tidal turbine in Admiralty Inlet, Puget Sound. This study 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 on bird strike risk comes mostly 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 influence 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 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. Measures also include careful siting to avoid high-density and migratory waterfowl areas, breeding areas, migratory pathways of concern, and potential cumulative impacts.

Bat strikes by 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 the 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 creating a fish aggregation device (FAD), in which 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 the 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 a high level of agreement within the literature that marine energy devices will act as FADs. However, there is significant uncertainty surrounding the exact interactions this may cause and the influences it may have on individual species and communities (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, or the accumulation of marine organisms on structures. In particular, biofouling increases populations of organisms such as 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).

The 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 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. In general, effects were predicted to be small and localized (Boehlert et al., 2008; Polagye et al., 2011).

Effects on the physical environment

Marine renewable energy devices are designed to extract energy from the 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. 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) are limited due to the 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 estimating energy changes are limited, and there is much uncertainty surrounding the magnitude of impacts 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 (e.g. wave propagation, water column mixing, sediment transport) and some additional wind-related concerns. For example, offshore wind farms will produce a wind wake, but it is unclear what effects this may have on the physical environment. For example, offshore wind farms will produce a wind wake, but it is unclear what effects this may have on the physical environment such as on wave propagation. Given that wave generation occurs over much larger areas, it is uncertain how a wind farm may effect overall wave propagation. Clark et al. (2014) stated that impacts are uncertain (especially for large offshore wind farms), that 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 (Washington Coastal Marine Advisory Council, 2015). Current monitoring of offshore wind farms in Europe suggests 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. Washington Coastal Marine Advisory Council (WCMAC) members developed policy recommendations that include a survivability assessment for all new ocean structures, with requirements for plans and sufficient performance bonding to ensure site rehabilitation after use (Washington Coastal Marine Advisory Council, 2016).

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 the 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. Therefore, they are considered to be of low concern (Musial & Ram, 2010; Polagye et al., 2011). Large oil spills from collisions (e.g. supply vessels) would likely have a high impact on fish, birds, habitats, and marine mammals. However, 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 effects are highly site specific and depend 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 other potential future uses of the ocean, 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 related to usage of space. These can be direct conflicts in space that may result in temporary or permanent displacement or increases in the time or cost necessary to complete an activity. Spatial conflicts may directly impact the economics of an affected industry, which could lead to hardships within industries and the local communities which depend on them. The MSP assists in identifying the types of spatial conflicts present in the Study Area and recommends ways to avoid and minimize impacts from new uses (see Chapter 4: MSP Management Framework).

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 on project specific factors such as device type, the 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).

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 movement within the farms may be restricted for safety reasons. The first offshore wind farm in the U.S., 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 other offshore wind farms (33 C.F.R. § 165.20).

Some fisheries may be subject to more displacement/exclusion than others, possibly due to the gear type used by those fisheries. Impacts to various fisheries may also vary due to the nature of the fishery (e.g. a 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 (Industrial Economics, Inc., 2012).

It is impossible to know at this point how extensive impacts to Washington fisheries would be. 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 (e.g. seafood processors, maritime support) 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 BMP is the use of siting considerations to avoid conflict. This includes meeting with local fishing groups to avoid key fishing locations and seasons, maximize fishing access, communicate construction schedules, and discuss cable routing (Ecology and Environment, Inc., 2014).

Safety standards are another BMP, including recommendations for markings, radio use, and lighting, as well as procedures for emergency events. An environmental monitoring BMP includes monitoring procedures and incident reporting requirements. Ecology and Environment also recommended BOEM consider 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 enhancements to fisheries research (Ecology and Environment, Inc., 2014).

A study of several U.S. ocean regions (including the Pacific Northwest) identified numerous potential conflicts and avoidance and mitigation measures upon which BOEM's BMPs were based. This study 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 boaters may need to alter travel and destination patterns, and may experience 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. The 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 cultural and historical resources. Consultations with the State Historic Preservation Officer (SHPO) will be required if the project occurs in state waters and with the Tribal Historic Preservation Officer (THPO) for tribal lands. BOEM's regulations in 30 CFR 585, specifically those regarding renewable energy leases on the outer continental shelf, require a site assessment to identify historic properties.

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: avoiding spatial conflict 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 to 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., during fog and haze vs. on a clear day). Due to the height and size of wind turbines, offshore wind will likely have the greatest potential impact on viewsheds, 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. The majority or entirety of these devices 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 on and tolerances for viewshed alteration by marine renewable energy devices. Communities in Washington (Washington Coastal Marine Advisory Council, 2015), 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 traveled to see operating offshore turbines (as cited in Musial & Ram, 2010). Studies from Europe also suggest that individuals may become accustomed to the change in view over time, exhibiting less resistance to a project once it becomes operational. The ultimate effects of marine renewable energy projects on tourism will likely be highly site-specific. 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 on property values. U.S.-based studies on land-based wind farms cited in Musial and Ram (2010) 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 shoreside support infrastructure may also contribute to an altered coastal viewshed. Projects that could impact culturally important viewsheds would require consultation with THPOs and tribal governments (36 CFR § 800.2).

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 the waves used by surfers, wind used for sailing activities, and coastal zone mixing that affects water quality. As described within the section on effects on the physical environment, 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 the likelihood of impacts increasing with the size of the offshore wind array and the amount of energy extraction. However, 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). This could potentially affect the 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 effects 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). 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 (e.g., 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). One of the requirements for the MSP is to include a framework that coordinates state agency and local government review of proposed renewable energy development to streamline the process (RCW 43.372.040(6). This is addressed in Section 4: MSP Management Framework. 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 from 3 nautical miles to 200 nautical miles offshore.[6] BOEM has a flexible process for establishing leases for renewable energy which generally occurs in four phases: planning and analysis, leasing, site assessment, and 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 on the OCS in 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), can issue authorizations for marine renewable energy projects in Sanctuary waters.

[6] State jurisdiction lies between 0 and 3 nautical miles offshore.

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 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 § 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 licensing 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 on 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 § 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 § 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. The EPA also reviews Section 404 permit applications.

Marine Renewable Energy Technical Suitability Within the MSP Study Area

To support the MSP, PNNL produced a report in 2013 analyzing the potential technical suitability of the MSP study area for various offshore wind, wave, and tidal current energy devices. As required by RCW 43.372.040(6)(c), the report included a series of maps which indicated the relative technical suitability of devices by location.[7] PNNL created these maps by evaluating site suitability using several criteria, which were grouped into three categories: site quality, shore-side support, and grid connection. 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. The analysis evaluated potential technical suitability only,[8] 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 in MSP Study Area 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 relatively suitable locations for tripod and jacket, monopile, and floating foundation technologies are shown in Maps 43, 44, and 45 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 the Electric Power Resource Institute (EPRI) (2011) estimates that Washington has approximately 19% of the available wave energy resource on the West Coast. Wave energy technical suitability in the MSP Study Area was analyzed by Van Cleve et al. (2013) for four device groups: nearshore, nearshore M3, mid-depth, and deepwater wave. Maps 46, 47, 48, and 49 show locations with potential technical suitability for nearshore, nearshore M3, mid-depth, and deepwater 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] Technical suitability was based 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. PNNL's suitability assessment combined all tidal current energy device types to create one tidal energy site suitability map, shown in Map 50. 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. This assessment did not include suitability based on conflicts with current uses or ecological habitats. Suitability in this analysis is relative, meaning that a site with a high suitability score may not necessarily be an appropriate site. However, this analysis provides a valuable first look at what areas may present possibilities for renewable energy based on technical factors. The suitability results show a greater number of areas with higher suitability for renewable energy development off the southern half of the Washington coast than the northern half, and many sites are suitable for more than one device type (Maps 43-50).

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 51). The authors note that distance to shore support (service ports and deepwater ports) also influences this pattern. Areas most suitable for marine renewable energy development are within 25 miles of the coast. There are limited areas with suitability for tidal current enegy 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

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). 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 the 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 impacts from climate change may pose risks or challenges to marine renewable energy infrastructure in the MSP Study Area. As described in Section 2.11: Climate Change, scientists project that storms will increase in intensity and frequency as a result of climate change. This is also likely to include increasing wave heights and potentially changes in wave direction in the MSP Study Area (Miller, Shishido, Antrim, & Bowlby, 2013). Marine renewable energy infrastructure in the MSP Study Area would be exposed to any increases in storm energy and frequency that result from climate change. Extreme winds carry an increased risk of turbine damage and the resulting cost of repairs. Extreme weather may cause seafloor sediment to become more mobile and cause foundation instability, structural issues, and cable exposure (Diamond, 2012).

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 section, 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). Tribes must still go through all applicable federal permit processes.

While the southern half of the MSP Study Area may be more technically suitable for marine renewable energy development (including the proximity of support and grid infrastructure), this area is also subject to heavy ocean use from marine industries including shipping and non-tribal fisheries (Map 40 and Map 17). 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 state of 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 the relatively advanced stage of offshore wind technology development, Industrial Economics, Inc. (2014) reported that the likelihood of offshore wind development along Washington's Pacific coast over the next 20 years is still limited.

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). There is 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 an 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 the 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 (e.g. 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. 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[9] (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 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, meaning energy generation is not constant throughout time. This creates challenges for integration into the grid. The Northwest electricity industry[10] 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). This indicates the capability to integrate marine renewable energy resources, particularly in light of greater capacity factors being 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[11] (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 are

[9] Construction and equipment requirements will vary between offshore wind foundation technology types.
[10] The Northwest electricity industry includes organization such as BPA, Puget Sound Energy, and other major local, state, and regional utility organizations.
[11] 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.

skeptical as to whether the investment into these updates will benefit 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. 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 on 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). These industries 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. Recommendations within the MSP are based on avoiding and minimizing conflicts with existing ocean uses. These recommendations may influence the location, extent, and process for marine renewable energy development. It is a goal of this Marine Spatial Plan to 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 an increased likelihood of 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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Laws [Source type 5]

Revised Code of Washington (RCW)

Energy Independence Act of 2006, RCW 19.265
Marine Waters Planning and Management, RCW 43.372

United States Code (USC)

National Historic Preservation Act, Title 54 USC Section 106

Regulations [Source type 7]

Code of Federal Register (CFR)
Federal Power Act, 18 CFR Parts 4 and 5
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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 is the culture or growing of fish, shellfish, or other aquatic plants and animals, and has been a part of Washington's landscape for thousands of years. Existing aquaculture activities provide important sources of food and livelihood for many Washingtonians, including native peoples.

No aquaculture activities are currently taking place outside of the estuaries in the MSP Study Area. The potential expansion of aquaculture activities into ocean waters beyond the estuaries becomes increasingly possible with technological advancements. The expansion of aquaculture into deeper, offshore waters is driven by the ever-increasing demand for high quality protein and the limited area 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, compatibility with existing uses, and ability to address environmental impacts.

Summary of History and Current Use

Offshore Aquaculture

There are 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 challenges to offshore aquaculture, and require technologies that can withstand these conditions.

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 produces mainly 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 along Washington's Pacific coast, please see Section 2.5 of the Marine Spatial Plan, as well as the Aquaculture Sector Analysis (Industrial Economics Inc., 2014) and economic analysis report (Taylor, Baker, Waters, Wegge, & Wellman, 2015).

In general, coastal aquaculture 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 better 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 and operations around the world currently employ a limited number of technologies and techniques. However, there are examples of 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 on a commercial scale (Lovatelli et al., 2013). Each species has its own specific husbandry techniques and technology needs. The following sections briefly describe current and emerging technologies for three species categories: finfish, shellfish, and marine plants. It provides context 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). British Columbia also has a major Atlantic salmon net-pen industry (Fisheries & Ocean Canada, 2013) and the species also is raised in deep water and weather-exposed sites in Norway and Chile (Holmer, 2013). While offshore Atlantic salmon cultivation could be pursued in our ocean waters, public concern about these operations has grown following the August 2017 collapse of a salmon net pen near Cypress Island where about 150,000 adult non-native salmon escaped. This includes concerns about the potential impact of Atlantic salmon on threatened or endangered native Pacific salmon, and possible harm to water quality.

A few current and emerging cage designs may be 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 underwater. These cages are often composed of flexible netting attached to a floating collar at the water's surface. This flexible collar will float and bend to adapt to rough waves (Forster, 2008). Many exposed offshore sites have used floating net cages but there are limitations on their use. The strength and endurance of these cages are limited, and there are issues with volume loss, worker safety, and other operational limitations (Ladenburg & Sturges, 1999). It is anticipated that nearshore net pen technology will continue to evolve and be adapted for offshore operations.

Other cages use rigid platforms with surface access that are 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 immense in size (Ladenburg & Sturges, 1999).

While surface cages are more exposed to rough sea surface conditions than submersible cages, they are highly attractive because they provide 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 during rough sea conditions. 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 used 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

Shellfish culture in coastal Washington currently consists mainly of 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 the northeastern United States (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).

Technology is currently more advanced 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 in unit value (Lovatelli et al., 2013). Offshore seaweed culture methods are similar to those for shellfish. Seaweed is 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, which 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 (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 demand for seafood. The growing world population combined with the recommendations of health experts about the benefits of seafood consumption will continue to increase the demand for seafood, and 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 greater potential to meet this demand than coastal aquaculture, as space limitations and 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. Just as with current coastal aquaculture operations, offshore aquaculture products would be subject to U.S. and Washington State health and environmental regulations and enforcement, whereas other countries have varying levels 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 operations are located further from shore, they are 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). However, future impacts on productivity in offshore aquaculture from ocean acidification and climate change will need to be evaluated.

Economic Benefits

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 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 those associated with 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 over producers in other locations (Anderson & Forster, 2008).

The overall impact of upstream and downstream products and services (e.g. cage manufacturing, juvenile supply, processing, restaurants) may be five to ten times greater 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 Pacific coast may be well positioned to realize many potential local and regional economic benefits associated with offshore aquaculture.

Potential Use Compatibilities

Offshore aquaculture has the potential to be compatible or have limited conflict with some established and potential future uses in the MSP Study Area. 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 section on potential impacts.

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). The decreased visual impact from facilities with increasing distance from shore is but one example of this (Ladenburg & Sturges, 1999).

Potential Environmental Impacts

Potential environmental concerns include impacts on water quality and interactions between the aquaculture structures and marine organisms, such as sharks, pinnipeds, seabirds, and wild fish.

Water Quality

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 and remediated through fallowing practices. Offshore sites are expected to exhibit lesser changes in sediment, yet appropriate siting to minimize changes to the sediment is highly recommended (Holmer, 2013; Price & Morris, 2013). Offshore sites should also avoid sensitive deep-sea 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).

Chemical contaminants such therapeutants,[1] antibiotics, and antifoulants[2] are consistently identified as concerns for marine aquaculture, but the use of these products has drastically declined over the last 20 years (Price & Morris, 2013). Experts predict that the use of therapeutants will be further decreased in offshore aquaculture (Holmer, 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 and pesticides from feed and antifoulants can also accumulate under cages. Studies show that heavy metal concentrations are low and typically bound to the sediment (Price & Morris, 2013).

Marine Mammals

There are very few verified instances of marine mammals being injured or entangled in aquaculture gear. However, entanglement, habitat exclusion, marine debris, underwater noise disturbance, and behavioral alterations have been identified as potential impacts to marine mammals (Price et al., 2016).

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[1] Therapeutants are medications used to treat parasitic, viral, fungal, and bacterial infections as well as to treat aquaculture facilities (Price & Morris, 2013).
[2] Antifoulants are treatments used to control or eliminate the growth of marine organisms on aquaculture cages, ropes, and structures. (Price & Morris, 2013).

It is generally believed that marine mammals that can echolocate (toothed whales, dolphins, and porpoises) can identify offshore aquaculture structures and navigate around them. Baleen whales that do not echolocate are likely at a higher risk of entanglement because they rely on visual and audio cues to identify structures in the water (Price et al., 2016). Management strategies to avoid impacts can include selecting locations for aquaculture facilities that minimize the likelihood of overlap with migration routes or critical habitats (Price et al., 2016).

There are no reported interactions of pinnipeds with offshore shellfish farms, likely because they do not commonly feed on shellfish (Price et al., 2016). However, there are reports of negative interactions between pinnipeds and finfish farms. Pinnipeds can cause financial losses to the fish facilities through direct predation, or by causing stress to fish and escapement due to predator attacks (Price & Morris, 2013). Farm management practices designed to decrease pinniped interactions include net tensioning, adding false bottoms to avoid predation from below, removing of dead fish, and using antipredator nets (Price et al., 2016).

Sea Turtles

The main concern for interactions between sea turtles and offshore aquaculture is the threat of entanglement with nets, lines, or other floating equipment. There have been a few documented instances of sea turtles being entangled in shellfish aquaculture gear. Potential management recommendations for the reduction of negative interactions include using rigid netting material for the cage, keeping mooring lines taut, and removing any loose lines or floating equipment (Price et al., 2016).

Fish

Wild fish may aggregate around fish cages. They may be attracted by the feed or use the structure for protection from predators. Escape of cultured fish and the potential for disease and parasite transmission from cultured fish to wild fish are concerns (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 to prevent the spread of disease in the event of an outbreak (RCW 77.60; RCW 77.115; WAC 220-370; 9 CFR 53.10; 9 CFR 71.2; 9 CFR 93.900-906). Pathogens and parasites can be transferred between farms and wild fish in both directions in open production systems, and disease can also be transferred from farm to farm (Holmer, 2013). Offshore sites are also expected to have a reduced risk of transmitting diseases and parasites because of the potential increased distance between operations. However, the risk would also depend on distance to major migration routes, distance to feeding and spawning grounds, and the attraction of wild fish to the cages (Holmer, 2013).

Cultured strains of fish like salmon have lower fitness in the wild, so escape and interbreeding with wild populations can reduce the overall fitness of natural populations (Holmer, 2013). The interactions between wild and cultured populations can be exacerbated by a number of factors. For example, if salmon escape at the same time that wild populations are migrating to their spawning grounds, this could have significant direct effects through interbreeding and indirect effects through ecological competition with the wild fish (Holmer, 2013).

Birds

The entanglement of seabirds at shellfish farms is a concern. At nearshore farms birds are observed using the area for perching or feeding on epifauna growing on above-water structures. At an offshore mussel farm neither of these activities would be expected, as the structures are submerged (Price et al., 2016). At marine finfish farms seabirds are reported to congregate nearby, but are not a significant predatory threat as they typically only scavenge mortalities or take fish during transfer or harvest. The biggest risk to the seabirds is entanglement in the cage or in anti-predator nets (Price et al., 2016). Some of the management options to avoid negative impacts to seabirds are to select sites carefully to avoid critical breeding and foraging habitats and migration routes (Price et al., 2016).

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 wild capture fisheries market. 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, which 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, global 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 regardless of whether 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 potential future uses of Washington’s ocean. Some concerns related to spatial conflicts include competition with commercial fisheries, recreational fisheries, recreational activities (e.g. boating, aesthetics), shipping, military uses, cable installation, marine animal migration routes, mining, dredging, and dredge disposal (L. E. Buck, 2012; Hildenbrand & Feldner, 2008). 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 are most often associated with finfish aquaculture. These include conflicts with 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 conflict with the goals of marine reserves. In addition, mooring lines from cages and longlines may pose a risk of animal entanglement. Interactions with seabirds, pinnipeds, and other marine mammals may pose conflicts, particularly along major migration routes and aggregation sites (Price & Morris, 2013).

Future Trends and Factors

Currently, no offshore aquaculture exists along Washington's Pacific coast. However, there is potential for offshore aquaculture in the future. 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). However, the realization of offshore operations largely depends upon economic feasibility and the availability of technology to support 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 for up to 100 m (Kapetsky, Aguilar-Manjarrez, & Jenness, 2013) and most sites may be restricted to 75 m or shallower due to prohibitive mooring costs (Forster, 2013). On the other hand, deeper water generally indicates fewer environmental impacts. 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 potential future uses may occur. Therefore, locating offshore aquaculture at locations that will avoid significant conflict with established uses 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 structures 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 on 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. 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 participants recognized that there is real potential in Pacific Northwest waters, some challenges exist such as the number of stormy days along this coast, competition concerns from 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 operations (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 are 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, it becomes more likely that aquaculture will expand into offshore waters (Knapp, 2008a, 2013).

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2.10.3 Dredging and Dredged Material Disposal

Dredging and dredged material disposal are essential activities that are 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 in 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 with sand and mud over time. Dredging removes this material, which is then disposed of at in-water or upland 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 dredged material disposal have 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 52) and at the Mouth of the Columbia River (Map 53). The navigation channel in Grays Harbor supports the Port of Grays Harbor marine terminals and associated facilities, and the marina in Westport. 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 five small port facilities within Willapa Bay (Map 54). The Port of Willapa Harbor owns and operates Raymond Port Dock, Bay Center Marina, Tokeland Marina, and South Bend. The Port of Peninsula operates the marina at Nahcotta. Two tribal-owned facilities also exist within the MSP Study Area, the Quinault Marina[2] in Ocean Shores and the Quileute Marina in La Push (Map 31).

The disposal of dredged material is a critical component of dredging activities. Dredged material is disposed at in-water or upland sites. Current federal policies make disposal of material at in-water sites is generally the economically preferred alternative for the U.S Army Corps of Engineers. However, there is an expressed interest by agencies and communities to keep clean sand in our active coastal littoral systems (i.e. placing the sand on the beach or as close to the beach as possible). Sediments determined to be unsuitable for in-water disposal, such as those from chemically contaminated sites, are disposed of at approved upland locations (Dredged Material Management Office, 2016a).

[1] Ports along the Columbia River are outside of the MSP Study Area.
[2] The Quinault Marina in Ocean Shores is currently closed to public access due to needed repairs.

The Washington Department of Natural Resources (DNR) manages four in-water disposal sites within the MSP Study Area, two for Grays Harbor (Map 52) and two for Willapa Bay (Map 54). These sites are all categorized as dispersive, meaning that dredged material will eventually disperse and leave the immediate site rather than staying in place. Actively used sites are monitored by the Dredged Material Management Program (DMMP) agencies regularly for volume capacity and other parameters (Dredged Material Management Office, 2016a).

Beneficial use sites are disposal locations where dredged material is deposited for some specific beneficial purpose or reuse of the material.[3] Beneficial use projects are important because they offer a natural alternative to protect vulnerable coastal areas from the effects of natural hazards (e.g. erosion and flooding), help maintain beaches and dunes, and maintaining/enhancing habitat. Beach nourishment, done properly, can also increase recreational and subsistence use of these areas. There are a few beneficial use sites within the MSP Study Area, including two nearshore DNR/Corps managed sites at Grays Harbor (South Beach and Half Moon Bay disposal sites) and a few on-shore beneficial use projects (Quillayute River, Half Moon Bay, 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 dredged material over deep water disposal (Dredged Material Management Office, 2016a; 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 used within the Columbia River and, since 2009, for some dredged material disposal in Willapa Bay (Dredged Material Management Office, 2016a). The Westport Marina has also been approved for flow lane disposal.

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). The third 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 dredged 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 (U.S. Army Corps of Engineers, 1982, 2014b). The Corps continues to be responsible for annual navigation channel maintenance in Grays Harbor. In October 2016, dredging began to deepen the navigation channel from -36 feet Mean Lower Low Water (MLLW) to -38 feet MLLW, the legislatively authorized depth, and is expected to be

[3] Upland beneficial uses of dredged material are not discussed within the MSP as they are not related to the MSP Study Area.

completed in late 2018 (see the Future Trends section below). Dredged material from the deepening will be placed in either the South Jetty or shifted Point Chehalis disposal sites. Material unsuitable for open water disposal will be placed in a suitable upland site (U.S. Army Corps of Engineers, 2016).

The Corps uses six sites for disposal of the Grays Harbor navigation channel maintenance dredged material (Map 52). Four of these sites are in-water disposal sites. The DNR-managed Point Chehalis open water disposal site is the most heavily used site for dredged material disposal. It is located north of Point Chehalis and includes part of the navigation channel (U.S. Army Corps of Engineers, 2014b). The second DNR-authorized open water disposal site is the South Jetty site, located directly north of the South Jetty's western portion (Dredged Material Management Office, 2016a). 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 or when marine conditions make disposal at South Jetty too dangerous (U.S. Army Corps of Engineers, 2014b).

Two nearshore beneficial use sites are managed by DNR and the Corps in Grays Harbor. The South Beach beneficial use site receives sediment from the bar and entrance reaches, in an attempt to slow erosion along South Beach and the south side of the South Jetty. The second nearshore beneficial use site is the Half Moon Bay site (Map 52). 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 52). This offshore deep-water site is used very infrequently and is listed as inactive in the 2016 DMMP user manual (Dredged Material Management Office, 2016a).

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). Opportunities for placement at this site are limited due to lack of equipment. Periodically, sediment has been excavated from this site to nourish the dune along the 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 of Grays Harbor is responsible for dredging the terminals and marina boat basin. The terminals are currently dredged every year by a contractor. The dredged material is disposed at the Point Chehalis DNR disposal site. The Westport Marina was last dredged during its expansion in 1980 (M. Horton, personal communication, October 22, 2104). It has received a suitability determination and is scheduled to be dredged within the next two years (U.S. Army Corps of Engineers, 2017). The Corps is also planning on dredging the two federally authorized entrance channels into Westport Marina in 2018. 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 the 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 of the channel and -48 feet

MLLW on the south side. The bar at the MCR is considered 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). The MCR navigation channel dredging and current dredged material disposal sites are outside of the MSP Study Area. However, 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 dredged material from the MCR. Benson Beach is located directly north of the North Jetty (Map 53). The 2011 RSMP recommended Benson Beach because this location was expected to have the greatest benefits to beach and drift restoration in the area. In 2010, a project placed approximately 400,000 cubic yards of dredged material from the MCR onto the Benson Beach intertidal area. 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 project as it requires additional incremental funds for use. Costs and safety concerns are barriers to the future use of this site.

However, the Corps, in cooperation with other members of the interstate/interagency Lower Columbia Solutions Group, is in the process of identifying the location of a new nearshore dredged material placement area located in the Pacific Ocean off of the North Head, north of the MCR in Pacific County, Washington (US Army Corps of Engineers: Portland District, 2017). Surveys are planned in approximately 5.25 nmi2 (18 km2) study area. Water depths in the study area range from 30 to 65 ft (9 to 20 m). Based on recent hydrosurveys and knowledge of the site, the predominant substrate is likely sand; no rocky reefs are anticipated within the study area.

This proposed site near the North Head is referred to as the North Head Site (NHS). The addition of a nearshore disposal site within the MCR's current disposal network will:

1. Provide additional long-term dredged material disposal options for the MCR dredge material disposal site network;
2. Increase the efficiency of dredging operations by utilizing sites closer to the federal navigation channel;
3. Protect the existing jetties that are a part of the MCR navigation system;
4. Beneficially use dredged material by keeping it within the MCR nearshore littoral zone.

Shoalwater Bay Project

The Shoalwater Bay Shoreline Erosion Protection project utilized 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 (a.k.a. Washaway Beach). 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 MSP Study Area are provided recognizing their importance to the coast and for their influence on dredging and dredged material disposal activities.

Federal funding for small ports

The Corps dredges pursuant to the Rivers and Harbors Act (33 U.S.C. § 403, et. seq.). Appropriated funds for federal navigation projects are filled by the Harbor Maintenance Trust Fund. For the past several years, small coastal harbors have had to compete directly with larger coastal ports across the nation for federal funding from the Harbor Maintenance Trust Fund (U.S. Army Corps of Engineers, personal communication, September, 2014). This has resulted in variable and uncertain funding for small port dredging (U.S. Army Corps of Engineers, personal communication, September, 2014). The extensive costs of equipment and operation can create a significant challenge for small ports in securing 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).

Additional discussion of ports and marinas can be found in Section 2.4: State 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 for fishing and oyster vessels. The Port owns and operates three water access facilities within Willapa Bay that require dredging at various frequencies for navigation maintenance: Tokeland Marina, Bay Center Marina, and the Raymond Port Dock (Map 54) ("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 has delayed dredging the main channel over the bar at the mouth of the Bay to the Willapa River since 1975 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. The Port has used this dredge to maintain the boat basin at Tokeland Marina, as well as the entrance channel which connects Tokeland to the deep-water channel. The 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 54) (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). Flow lanes are also 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 located on the Willapa Bay side of the Long Beach Peninsula (Map 54). 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 has not occurred since 1975, and the Corps has delayed dredging of the Ports' entrance channels since 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 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, located in the northern section of Washington's Pacific coast at the mouth of the Quillayute River (Map 55). The U.S. Coast Guard operates Station Quillayute River out of the harbor. The Quileute Tribal Council 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, and the most recent dredging activity was in 2015. The 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 from the outer channel is placed at several upland locations. The material from the inner channel and harbor is placed on the ocean side of Rialto Beach Spit for beneficial use for smelt spawning habitat (U.S. Army Corps of Engineers, personal communication, September, 26, 2014). It is also occasionally placed near the jetty near First Beach to stabilize erosion and for jetty maintenance and protection.

Significant ports outside of the MSP 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 the 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 dredged material 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 dredged material disposal methods and equipment

Material is removed from navigation channels and harbors using dredge equipment such as hydraulic or clamshell dredges. The material is then placed either in hopper dredges or in barges, which can transport the sediment to disposal sites and dump or pump the material directly to the placement location (U.S. Army Corps of Engineers, 2014b). Various methods can be used to release dredged material into a disposal site such as bottom-dump disposal, dispersed spraying, and pump-ashore disposal.

Bottom-dump disposal

Barges and hopper dredges are designed to be able to release dredged material from the hull, otherwise known as bottom-dump disposal. Bottom-dump barges and hopper dredges release the material within the boundaries of in-water disposal sites. This method of disposal can be performed at open-water and nearshore beneficial use sites. However, safely navigating 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 if conditions are not dispersive, 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) (Oregon Solutions et al., 2011). Thin-layer dispersal (also referred to as enhanced dumping) using the bottom-dump disposal method can be achieved by moving the vessel during disposal, thereby reducing the mounding of sediment on the seafloor. 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. Onshore placement can be achieved by a barge and conveyance or material can be directly pumped from a hydraulic pipe. To pump from a hydraulic pipe, the sediment is mixed with water to create a slurry and the slurry is pumped 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

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 as minimizing 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 it is therefore much costlier. 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 Washington 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"), Grays Harbor has two (north and south), and Quillayute has one (south).

Jetties are hard structures, built on shallow shoals and extending like fingers out into the water. They work by restricting the entrance and exit for the flow of water, increasing water velocity and creating a dispersive effect. 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 any shoals that may form despite the presence of the jetties.

Jetties at the MCR, Grays Harbor, and Quillayute have impacted sediment movement along the Washington 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 Cities of Ocean Shores and Westport. 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, sea dikes, 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 productive purpose (Dredged Material Management Office, 2016a). There are a broad range of uses for beneficial placement, such as erosion control, dune reconstruction, beach nourishment, and other purposes. Alternatively, 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. It can 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 some projects, such as MCR, Grays Harbor, and Quillayute, a network of sites is used to optimize the opportunities for beneficial placement of material and to minimize the use of deep-water sites. Beneficial sites are typically chosen with the goal of maximizing benefits to beach erosion protection, habitat improvements, and jetty protection while also minimizing the conflicts to users of the area, all 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 beach erosion mitigation 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, and have timing constraints, safety and logistical considerations, and 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 Benson Beach, have added benefits of avoiding user conflicts for navigation and minimizing potential impacts to Dungeness Crab and the associated fishery. Onshore projects, however, are typically estimated to have higher costs and time requirements and different equipment needs than nearshore projects. This creates 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

Dredged material disposal sites utilized by the Corps are actively monitored and managed for capacity. Open water sites in the MSP Study Area 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 dredged material 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 using a number of parameters, including historical baseline data, wave models, and present conditions. The natural environment (e.g. waves, storms) can influence 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 dredged material in deep-water 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 the volume of dredged material to be disposed (Coast & Harbor Engineering, 2011). Along the Pacific coast of Washington, 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, 2016a, R. Chaffee, personal communication, October 1, 2014; U.S. Army Corps of Engineers, personal communication, September, 2014).

Impacts from Dredged Material Disposal

Environmental impacts from dredged material disposal

The study of dredged material disposal impacts to ocean habitat and species has a long history on the Washington coast. The Lower Columbia Solutions Group (LCSG) 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 as 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 dredged material 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 MCR and Grays Harbor are important breeding and nursery habitats for Dungeness Crab, which is an important and valuable fishery in the region (Oregon Solutions et al., 2011; U.S. Army Corps of Engineers, 2014b).[4]

Concerns highlighted in 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 from the 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). 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).

[4] The Dungeness Crab fishery is discussed below in the section on human use conflicts with disposal.

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 of the deposition of the dredged material, and acoustic tagging of crab to track crab survivability and behavioral responses. This information will be used to ground-truth laboratory tests on the effects of dredged material disposal on Dungeness Crab. It 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 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; 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).

Razor Clams and other benthic species

Within the LCSG, some participants raised concerns about the effects of dredged material disposal on Razor Clams (*Siliqua patula*). Concerns were related to subtidal Razor Clams because they have limited ability to move horizontally (Oregon Solutions et al., 2011). A study by Vavrinec, Kohn, Hall, & Romano (2007) testing adult Razor Clam mortality from dredged 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 dredged material 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 *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 invertebrates such as polychaetes, mollusks, and echinoderms are temporary. These effects are 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 the Half Moon Bay Beach and South Beach sites during sand placement to address 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 such as juvenile salmon and Green Sturgeon. The LCSG (Oregon Solutions et al., 2011) anticipated that the potential impacts to these fish are likely low as they can move away from the affected area. The 2011 RSMP recommends monitoring for salmon and other species like flatfish and bottomfish. Due to the variability of these populations in specific areas, the effects of dredged material disposal 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 birds 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 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 about potential impacts of dredged material disposal on marine mammals. The RSMP anticipated a low potential impact to marine mammals from dredged material 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 Dungeness Crab fishery is well-established and 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, between Grays Harbor and the MCR region.

The uncertainty surrounding the effects of dredged material disposal on Dungeness Crab in shallow water has driven concerns about dredged material disposal in areas heavily used by crab fishermen. Representatives of the Dungeness Crab fishing industry have voiced strong concerns about the potential effects of dredged material 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 dredged material 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).

Concerns over the impacts of dredging and dredged material disposal on Dungeness Crab have also influenced management decisions in Grays Harbor. To help determine which disposal site is used, the Corps has conducted pre-disposal crab surveys in the past at the two beneficial use sites; South Beach and Half Moon Bay. Results of these studies have been used to implement management practices that mitigate impacts of disposal in areas with high concentrations of crab and to avoid interference with the crab fishery. The Corps also considers the presence of crab pots in the South Beach area when planning and conducting dredging and disposal activities (U.S. Army Corps of Engineers, 2014b).

Navigational safety

Wave amplification, which can be caused by the mounding of dispersed dredged material, has occurred historically at MCR sites. Navigational safety is a key priority in disposal site capacity management and can be negatively impacted by changes in wave height (Oregon Solutions et al., 2011). The joint EPA/Corps Site Management and Monitoring Plan for Lower Columbia dredging and disposal activities requires avoiding dredged material mounding that could cause excessive wave amplification. Results from science and policy workshops summarized in the MCR Regional Management Plan recommended that a maximum threshold of 10% wave amplification over baseline conditions resulting from mounded disposed material 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 dredged material 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. Strategies for the program include bathymetric surveys, assessing mound-induced wave amplification, using rainbow spray, monitoring shoaling in the navigation channel, and conducting 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 dredged 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 dredged material 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 indicates that this impact would be temporary and that recreation and tourism would benefit in the long term by reducing long-term erosion impacts (U.S. Army Corps of Engineers, 2012a).

Permitting Dredged Material Disposal

The management of dredged material disposal is important for human and environmental health and safety in Washington's waters. Between 2000 and 2016, 28.1 million cubic yards of dredged material were disposed at the Grays Harbor and Willapa Bay disposal sites (Dredged Material Management Office, 2016b). Between 2000 and 2012 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 dredged material disposal. Disposal sites in Washington waters are designated by one of three agencies: the EPA, the Corps, or DNR. The specific process for disposal permits and authorizations varies slightly depending on which agency designated the site and whether the project proponent is the Corps or a private entity. However, environmental review for water quality,[5] 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 involving in-water disposal in Washington (Dredged Material Management Office, 2016a). 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 to determine suitability for in-water disposal. Sediment evaluation requirements must be met prior to obtaining any permits (Dredged Material Management Office, 2016a).

Regardless of who designates the disposal site, dredging and disposal operations require approval from various federal, state, and local authorities. Federal permits include Rivers and Harbors Act Section 10 permits and Water Quality Act Section 404 permits issued through the Corps. The project proponent must also conduct an Endangered Species Act Section 7 consultation with NOAA Fisheries and possibly the U.S. Fish and Wildlife Service. For dredged material 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 does comply with all public notice, federal consultation, and state requirements (Dredged Material Management Office, 2016a).

Several state agencies play a regulatory and policy role in dredged material 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, a Sediment Management Standards anti-degradation policy evaluation, 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 DNR requires project proponents to obtain a disposal site use authorization prior to disposal, if utilizing a DNR-authorized site. Local governments, through their local SMP, may require a Shoreline Substantial Development Permit, Exemption Letter, or

[5] 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)].

a Conditional Use Permit (Dredged Material Management Office, 2016a; 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, 2016a). 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, 2016a).

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 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 during project review (Dredged Material Management Office, 2016a). 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, 2016a). Project proponents can be responsible for monitoring for increases in turbidity outside of an established mixing zone (R. Chaffee, personal communication, October 1, 2014).

Dredged material disposal on tribal land also requires a tribal authority nexus. In the MSP Study Area, the Corps works with the Quileute Tribe for dredging of the Quillayute River at La Push and for dredged material disposal at designated locations at Rialto and First Beaches. The tribe issues a yearly permit to the Corps to authorize disposal locations (Quileute Tribe, 2014).

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 various 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. In 2015, the Corps approved construction, which began in October 2016. This dredging will improve navigation for deep-draft vessels by reducing tidal delays and tidally-related draft restrictions experienced by vessel traffic (U.S. Army Corps of Engineers, 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 dredged material disposal sites within the Study Area.

Dredging for maintenance and deepening will produce approximately 3.5 million cubic yards of material. Suitable dredged material from the deepening will be placed in either the South Jetty or shifted Point Chehalis disposal sites. Approximately 22,000 cubic yards of material that has been deemed unsuitable for open water disposal will be placed in a suitable upland location (U.S. Army Corps of Engineers, 2016).

To accommodate the additional amount of dredged material from the 2-foot deepening of the Grays Harbor channel, the Corps is undertaking a one-time 1,000 foot north-northwestern shift in the Point Chehalis open-water disposal site. Dredged material from the initial deepening activities will be placed within the shifted disposal site. This shift is intended to take advantage of deeper water and more favorable hydrodynamics for the additional capacity needed during the channel deepening construction year. Additionally, dredged material disposal from the deepening will take place over a period of three years and four separate work windows, allowing time between the work windows for the disposal site to flush. Dredged material from subsequent annual maintenance dredging will be placed in the regularly 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 to keep it within the scour channel. DNR will evaluate use of the shifted site prior to the next shoreline permit application (C. Barton, personal communication, March 24, 2017).

Another potential small change in dredged material disposal locations within the Grays Harbor area is related to actions to control erosion and reduce 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). Due to recent increase in erosion, Westport is exploring options for beneficial use of dredge materials (Washington Department of Ecology, 2017).

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 dredged material 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 the Columbia River

In the draft 2011 Regional Sediment Management Plan for the Mouth of the Columbia River (MCR), the LCSG identified two nearshore beneficial use sites for dredged material disposal that are within the MSP Study Area (Oregon Solutions et al., 2011). The first, Benson

Beach, was used in 2010 as an onshore project (Map 53) (see Summary of History and Current Uses: Mouth of Columbia River). Benson Beach is currently permitted by Ecology for use by the Corps for dredged material disposal, but it has not been used since the 2010 demonstration project. Onshore placement of dredged material requires more equipment, logistics, and time than 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 North Head in Cape Disappointment State Park. The 2011 RSM identified this site for its 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 representatives of the fishery initially identified it as a potentially acceptable beneficial use dredged material disposal site. However, the crabbing fleet now uses the North Head nearshore area frequently. Therefore, concerns about the effects to the Dungeness Crab fishery and navigational safety from disposal material mounding have led to strong opposition from some for the use of this site for dredged material disposal (U.S. Army Corps of Engineers, personal communication, September 25, 2014; R. Mraz, personal communication, September 10, 2014) (See sections on human use conflicts and environmental impacts). Several studies are currently being conducted in the North Head nearshore area. A test disposal event was planned for 2014-2015 to evaluate burial effects on invertebrates, currents, and sediment transport (R. Schwartz, personal communication, October 21, 2014). In September 2017, the Corps plans to conduct baseline benthic and epibenthic surveys for the proposed North Head Site (US Army Corps of Engineers: Portland District, 2017)).

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 by the EPA. As a part of the permitting process, the lead agency would conduct a National Environmental Policy Act (NEPA) process including environmental studies and consultations with NOAA Fisheries. 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 dredged material disposal. 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 Water Resources Development Act of 2016, which is Title I of the Water Infrastructure Improvements for the Nation Act (WIIN Act), passed in 2016. Section 1103 permanently authorizes emerging harbors to receive at least 10% of the Harbor Maintenance Tax funds that were provided in each fiscal year. Implementation guidance is pending. 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 cosmetics, pharmaceuticals, and biomedical research. Information on the history and current use, potential conflicts and compatibilities with other uses, permitting, and future potential in the MSP Study Area for these activities are discussed below.

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; anti-inflammatory agents used in 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 engage in 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 the 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 require various quantities of the target organism. Often compounds discovered within marine organisms are only available in small amounts per organism. Therefore, it may be necessary to harvest vast amounts of an organism to get the required quantity for testing and making a product available on the market. 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 one-time extraction may be all that is needed, as DNA replication techniques can be used in the lab. For natural products, however, additional and perhaps extensive collection 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). Ongoing research aims to increase the understanding of biosynthetic pathways to sustainably and

[1]Marine product extraction, as discussed here, does not include any extraction or harvest performed by the tribes.

cost-effectively supply marine extracted chemicals for pharmaceutical treatments (Baerga-Ortiz, 2009).

Land-based and in-water aquaculture have also been used to grow host organisms. For example, the mangrove sea squirt (*Ecteinascidia turbinate)*, 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 potential for shallow-water culture of deep-water sponges. However, other target compounds from deep-water host organisms may require a specific pressure, temperature, or 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 that is 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 provide 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 concern over the sustainability and habitat impacts of marine product extraction. Conservation measures are recommended to ensure the sustainability of marine product extraction (Arrieta et al., 2010; Bruckner, 2002). Possible measures include harvest 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 may involve a continued, large-scale commercial harvest. Even in circumstances where a sustained harvest would occur, it is difficult to generalize conflicts as they would depend upon the organism harvested, the method used, the 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 220-200-150). 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 entities like processors or research labs 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 on fishery management (RCW 77.70.160). Within five years, the WDFW director would submit a report to the Washington 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 Washington's coast, and to permit the transport and/or sale of organisms harvested in state or federal waters into Washington. 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 in marine product extraction in federal waters off the Washington coast, WDFW would likely have a role in permitting and management.

Within the tribal usual and accustomed areas (U&As) off the coast, any extraction of marine animals must involve consultation with the appropriate treaty tribe (depending on the location of the extraction and that tribe's treaty area) and the development of a management plan between the state and tribe (See Section 1.6 for more details on tribes and tribal treaty rights).

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 the extraction of marine organisms for commercial products from state-owned aquatic lands must apply for use authorization from DNR.

Future Trends and Factors

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 that for 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 Washington's Pacific coast is unclear. Based on the literature, it does not seem likely that the Washington coast is a primary target for marine bioprospecting. However, Washington does have unique environments including hydrothermal vents, seamounts, and deep sea corals. Therefore, as new marine species are discovered and technology expands the depths to which the ocean is explored, it is entirely possible that novel chemicals and DNA sequences could be discovered within the MSP Study Area.

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2.10.5 Mining

A potential new use of Washington's Pacific coast is mining within marine waters for sand, gravel, or gas hydrates. This section provides context about operations, environmental impacts, use conflicts, and future trends for sand/gravel and gas hydrate mining in Washington. Gold mining, a current recreational 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 have 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 nourish 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 works with state and local partners and is updating evaluations for sand resources within BOEM lease blocks (Bureau of Ocean Energy Management, 2017).

Most in-water sand and gravel mining in Washington is currently limited to rivers. Much of the sand removed from rivers is for navigation or flood control. Very little mining is currently performed strictly to obtain and sell sand (M. Rechner, personal communication, November 20, 2014). There are a few mining companies that mine sand on the Washington 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 in the MSP Study Area is similar to sand mining activities conducted for beach nourishment on the Atlantic and Gulf coasts. The Army Corps of Engineers (Corps) dredged (mined) sand within Willapa Bay, and used the material to reconstruct eroding dunes at Shoalwater Bay. For more information, see the section on the Shoalwater Bay project in Section 2.10.3: Dredging and Dredge Disposal.

Within the MSP Study Area, 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 Parks finds it 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 few growers in the Long Beach area. 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 that used for navigation dredging and disposal. Mining for sand and gravel in marine waters 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 nourishment projects, the material is placed at a temporary nearshore holding and rehandling site near the nourishment project site. The material is then dredged again and transported by pipeline. Temporary storage and nearshore rehandling areas are becoming more frequently used on the Gulf and East Coasts, 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 using 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 lot 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. Multiple tugs then 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 may also have dump valves on the intake pipe to dump unsuitable 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 selling material for land-based uses also require shore-based facilities for storage, handling, and distributing the material.

Potential Use Benefits and Compatibilities

Sand and gravel mining is compatible with beach nourishment and coastal protection projects. Depending upon the location and the amount and type of material needed for a coastal defense project, mining may be the most practical and cost-effective alternative for providing the needed material. Climate change and associated sea level rise and increased frequency of coastal storms may increase the need for beach and dune nourishment 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 Section 2.10.3: Dredging and Dredge Disposal).

Sand and gravel mining may be partially compatible with fisheries and other navigational and recreational uses, because the mining is seasonal in nature. However, when overlapping in time and space these activities may not be compatible. More information is discussed in the potential use conflicts section below.

Environmental Concerns

No information was available regarding sand and gravel mining (dredging) impacts on offshore areas in Washington, as it is not a current use. The summary below describes the available information on 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) and drawn into the suction dredge. The amount of time needed for benthic species recovery is variable. Studies on the Atlantic and Gulf Coasts report that biomass and abundance recovery 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, studies at the Ports of Tacoma and Seattle show that benthic invertebrates recolonize disturbed sediments in substantial numbers within months (U.S. Army Corps of Engineers, 2014). Studies from the East Coast report that recolonization of dredged areas is similar to successional colonization from other disturbances (Michel et al., 2013).

Benthic organisms may also be impacted by pipelines used to transmit sand. Pipelines can directly displace and crush benthic invertebrates. These impacts may also be worsened by the 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 using rotational dredging, dredging areas expected to rapidly refill, avoiding the creation of deep pits, and leaving some areas undredged. These methods have yet to be tested (Michel et al., 2013).

Turbidity and deposition of sediments on the seafloor may also affect benthic invertebrates. Turbidity and deposition of finer materials like silt and 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 sand. 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 the timing of dredging activities (Michel et al., 2013).

The impacts of noise on benthic invertebrates remain largely unknown (Michel et al., 2013).

Fish 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. The South Atlantic Fishery Management Council, researchers, and other institutions have expressed concerns about the effects of offshore dredging on the ecological services sand shoals provide for fishery resources (Michel et al., 2013). Adult fish and mobile bottom-dwelling fish species are expected to be able to swim away from dredging activities. However, dredge equipment can suck in, or entrain, some species and cause injury or death. Higher risks to fish 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 bottomfish and loss of habitat (Michel et al., 2013).

There are many concerns surrounding impacts to fish and other mobile species from offshore sand and gravel mining, yet several data gaps exist regarding this topic. Most of the assessments of entrainment rates for fish and mobile invertebrates have been for shallow-water and estuarine dredging activities. A literature review summarized by Michel et al. (2013) reported that Dungeness Crab entrainment rates by hopper suction dredges in estuarine and river settings 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 redisposition of sediment from sand and gravel mining activities could pose risks of smothering eggs in bottom-dwelling fish spawning grounds and burying 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 may also potentially be impacted by sediment deposition over those habitats. Site-specific buffers around hard-bottom habitats are used to reduce impacts of offshore sand mining along the East Coast (Michel et al., 2013).

Water quality may decrease in deep dredge pits where water exchange 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 on fish populations. Potential effects from noise could include changes in behavior and loss of hearing (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 available assessing impacts from offshore sand mining activities on the East Coast. 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 seabirds would experience any of these impacts (Michel et al., 2013). The Environmental Impact Statement (EIS) 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). The effects of offshore sand and gravel mining (dredging) 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 changes in water quality. Vessel strikes can cause injury or mortality to whales, meaning mining may pose some increased risk to whales. However, dredge vessels are often slow moving, and East Coast dredging operations use mitigation measures to reduce risks 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 on 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 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 by disturbance of bottom habitats, turbidity, and deposition of fine sediments 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. Loggerhead, 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 available 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 a given sea turtle species’ life history, prey and habitat preferences, and behavior (Michel et al., 2013).

Ecosystem effects

As mentioned above, sand and gravel mining directly impacts bottom habitats and benthic species. However, the degree of these impacts on trophic systems and ecological interactions remains uncertain. Ecosystem impacts are difficult to measure. Food web models 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 due to 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 bottom-disturbing fisheries. The impacts from bottom-disturbing fishing can serve as a proxy for examining the potential ecosystem impacts of sand and gravel mining, although a few key differences exist. These differences include intensity of the activity, as sand mining may have a greater direct disturbance to the bottom habitat than bottom disturbance fishing. Spatial extent of the activity may also differ, because sand mining will likely be located at fewer sites and be 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 significant interest to those with interests in ecosystem based management, fishery commissions, and other groups (Michel et al., 2013).

Potential Use Conflicts

Commercial and recreational fisheries

Sand and gravel mining activities have the potential to conflict with current and potential new uses in the MSP Study Area. Conflicts with commercial and recreational fisheries have been studied for sand and gravel mining activities along the East Coast and in 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). Case studies indicate that the severity of these spatial conflicts varies by project location and fishery (Tomlinson et al., 2007).

The loss and damage of gear due to dredging operations, particularly fixed gear such as crab pots, 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 fishers due to the costs of replacement gear and loss of catch (Tomlinson et al., 2007).

Dredging activities and equipment may require fishers to alter navigation routes to their traditional fishing grounds, depending upon the location of material borrow and placement sites. This may increase time and costs for fishers, including increased fuel costs. Dredging operations may also directly restrict access or displace fishers 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. This can increase risk of collisions or inconveniences to fishers avoiding large dredge vessels. Effective communication and standard operating procedures regulated by the U.S. Coast Guard can mitigate these risks (Tomlinson et al., 2007).

Fishers in Florida (sand mining) and the United Kingdom (gravel mining) have also expressed concerns related to the impacts of dredging on fish and crab ecology and how it may influence stock availability and catch.

Conflicts with other uses

Sand and gravel mining operations may also potentially conflict with other current and future uses, particularly those that involve 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. Therefore, we can predict that other similar infrastructure, such as that for marine renewable energy or methane hydrate mining, will also not be compatible. Dredging activities could also uncover and transfer unexploded and discarded munitions. Historical munitions disposal sites are marked on nautical charts and the U.S. Army Corps of Engineers requires searching historical records of sites to prevent this issue (see Map 41) (Michel et al., 2013).

Dredging activities also directly conflict with prehistoric 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 prehistoric artifacts have been pumped ashore as a result of nourishment projects. Indirect impacts include the uncovering or burial of historical resources. BOEM is required by the National Historic Preservation Act to protect historical resources (16 U.S.C. 470). Geographic Information Systems (GIS) and sonar technology are used to survey potential borrow sites for historical resources. Buffers around U.S. historic sites in which 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 described in the literature, 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

The permitting requirements for sand and gravel mining are comparable to those for dredging and dredge disposal.[1] Permitting sand and gravel mining will involve both state and federal agencies. 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). For mining activities in state waters, DNR would be required to authorize the footprint for the activity and would charge fees based on the volume of material extracted. WDFW may require a Hydraulic Permit Approval. Local governments, through their local SMPs, may require a Shoreline Substantial Development Permit, Exemption Letter, or Conditional Use Permit (Dredged Material Management Office, 2013; Office of the Governor, 2006).

BOEM is the federal agency responsible for managing offshore non-energy minerals (primarily sand and gravel) on the outer continental shelf (OCS). They typically permit projects through noncompetitive lease agreements (Bureau of Ocean Energy Management, n.d.). BOEM must use the National Environmental Policy Act (NEPA) process to review environmental impacts using an environmental assessment (EA) or environmental impact statement (EIS). As a result of the analysis, BOEM may include measures in the lease or Memorandum of Agreement (MOA) to protect physical, biological, and cultural resources (Bureau of Ocean Energy Management, 2017). The Corps will also need to issue federal permits under the Rivers and Harbors Act Section 10 and Water Quality Act Section 404. As with dredging operations, the

[1] See Section 2.10.3: Dredging and Dredge Disposal for more information on permitting requirements.

permittee must coordinate with the DMMP or Portland Sediment Evaluation Teams, and will be required to conduct sediment suitability testing.

Future Trends and Factors

The potential for sand and gravel mining along Washington's Pacific coast is still unknown and BOEM has not yet done a suitability analysis. Overall, current sand demand is relatively low, but this could change due to increases in population and climate change impacts. There may be increased demand for sand to protect coastal communities, as these communities experience increases in the occurrence and magnitude of storms and sea level rise resulting from climate change. However, there is also the potential to use material already dredged for channel maintenance, potentially decreasing the demand for mined materials.

Gas Hydrate Mining

Gas hydrates are mixtures of gas and water that forms a solid ice-like structure under low temperature and high pressure conditions. The primary 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 the cooler conditions and high pressures within the sediment, the methane combines with water to form the hydrate (Bureau of Ocean Energy Management, 2012a).

The depth, temperature, and pressure range at which hydrates form is termed the hydrate stability zone (Consortium for Ocean Leadership, 2013). On the Washington margin, the hydrate stability zone begins at a water depth of about 500 meters (1650 feet). 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, 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.

Methane is a natural gas and can be used as an energy source. Methane hydrate resources are estimated by BOEM, the 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 in 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 the 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 provides context for potential gas hydrate exploration and production activities. It briefly describes the main tools currently used to explore for methane hydrates, and details some of the main components of offshore oil and gas equipment and supporting infrastructure.

Tools 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 send shock waves through the water and sediment, which refract back to either a floating or submerged receiver. The most common technology used for offshore oil and gas exploration are airguns, which transmit acoustic energy through the water column and into the subsurface. Seismic data is generally collected using multiple vessels (National Oceanic and Atmospheric Administration, 2013).

Well logging and logging while drilling use 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, semi-submersible, or a floating drill ship (Bureau of Ocean Energy Management, 2012b). Floating vessels are held over a well by either a mooring system or 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, with different designs capable of operating in various water depths. Fixed structures, semi-submersible structures, 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 in water over 7,000 feet deep (Office of Ocean Exploration and Research, 2010). Offshore processing facilities may also be located on or float 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 for and commercial production of methane hydrates.

Potential Use Compatibilities

There are likely no potential use compatibilities with gas hydrate mining in the MSP Study Area. Offshore oil and gas structures in the Gulf of Mexico do attract both pelagic and reef-associated fish species, so the structures could be attractive for recreational fishing (Bureau of Ocean Energy Management, 2012b).

Environmental Impacts

Environmental 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 that for oil and gas (Consortium for Ocean Leadership, 2013), environmental effects from offshore oil and gas production can be extrapolated for gas hydrate mining. Offshore drilling consists of multiple stages of activity including exploration, development, operation, and decommissioning. Each of these phases will have different impacts depending upon specific activities. 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 of and activities associated with 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 effects of any proposed gas hydrate mining on water quality, habitat, and species within Washington OCS waters will depend upon specific activities and intensities. Effects 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, waste disposal, vessel traffic, well drilling, and operational discharges. During offshore oil and gas drilling, drilling muds are used to lubricate and cool the drill bit and pipe. Some water- 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 National Pollutant Discharge Elimination System (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 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 water 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 the produced water concentrations that would be 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 systems, and moorings 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 resulting from exposure may have long-term consequences (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 those from supporting vessels, engines, or cargo transport vessels, may be similar.

Noise

Several routine offshore oil and gas operations produce unavoidable impacts from noise. These activities include exploration; construction activities such as pile driving and trenching; operational noise from platforms, ships, and aircraft; and demolition activities (Bureau of Ocean Energy Management, 2012b). A study by BOEM determined that seismic surveys may have a potentially adverse effect on marine mammals, sea turtles, fish, and commercial and recreational fisheries. Other survey activities were found to have negligible or no measurable noise impacts. Construction noises may disturb fish, sea turtles, marine mammals, and birds in the direct vicinity of the operation.

Gas eruption resulting from a 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 a species' hearing capabilities and the type, frequency, and intensity of noise generated (Bureau of Ocean Energy Management, 2012b).

Habitats

Benthic habitat can be disturbed by 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 has been estimated to be minimal in the Gulf of Mexico and Alaska. Offshore platforms can act as artificial reefs. They can be colonized by sessile organisms and attract mobile organisms, shifting the normal habitat of the open ocean.

Overall, in the Gulf of Mexico and Alaska pelagic habitat impacts are expected 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 the possible installation of pipelines. The habitat types affected and degree of impacts 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).

Marine mammals

Specific potential effects on marine mammals will depend upon the species and level of activity. 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 of or entanglement with solid wastes and debris; and 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

Offshore oil and gas activities 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 affecting their habitat, life stages, or behavior.

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 the 2012-2017 BOEM leasing program (Bureau of Ocean Energy Management, 2012b). Collisions with platforms in the northern Gulf of Mexico are estimated to occur at a rate of 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

Routine offshore oil and gas operational activities that have the potential to impact fish species include platform lighting, increased ship traffic, vessel discharge, and miscellaneous discharges. BOEM indicates that impacts on fish populations are expected to be minimal. 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 bottomfish, impacts are expected to be localized in the immediate vicinity of the activity. 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 platforms and exposed pipelines. Fish can also be attracted to oil and gas platforms to feed on colonizing organisms and other fish that have been attracted to the structures. This represents a change in community structure and fish behavior. The positive and negative effects of these fish aggregations will depend upon the life history of the fish species 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 the 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 using explosives can kill, injure, or disrupt the 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 from seismic surveys and bottom disturbance activities, and the release of drilling muds and cuttings. Invertebrates can be killed, injured or displaced by 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 require more time (Bureau of Ocean Energy Management, 2012b).

Drilling muds may contain chemicals toxic to marine invertebrates, but these effects may be species dependent. This may change the composition of the benthic community 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 that prefer hard-bottom substrates may colonize platform and pipeline structures. These structures may become habitat for native and introduced species (Bureau of Ocean Energy Management, 2012b).

Safety Hazards

Methane hydrates can be associated with both naturally occurring geohazards and those caused by human activities like drilling (Collett et al., 2015; Consortium for Ocean Leadership, 2013). Naturally occurring geohazards include slope instability and wide-scale gas venting, both of which can result from methane hydrate dissociation. When methane hydrate dissociates, it replaces the rigid component of the sediment with free gas and excess pore water, which can reduce sediment stability (Collett et al., 2015; Consortium for Ocean Leadership, 2013).

Site destabilization can also be caused by drilling or the installation of infrastructure on the seafloor. Methane hydrates occur at relatively shallow depths compared to most hydrocarbons, and therefore pose more of a hazard to shallow drilling and wells (Collett et al., 2015; Consortium for Ocean Leadership, 2013). Disturbance or heating of reservoirs can cause hydrates to dissociate. Overall, there is a lack of understanding of the risks of geohazards because there has been very limited field experience with methane hydrates. A small number of recent methane hydrate drilling programs were able to manage these risks by controlling drilling parameters (Collett et al., 2015; Consortium for Ocean Leadership, 2013).

Compared to the information available for oil and other gases, the literature did not include much information about the potential environmental effects of a catastrophic methane mining event.

Methane Releases and Climate Change

Methane hydrates form within a stability zone that is dependent upon temperature and pressure. When pressure decreases or temperature increases, hydrates can dissociate and release methane into the water column. Global climate change is influencing the temperature of some of the world's oceans, and could lead to increased releases 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 emissions 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 the air could contribute to further global climate change (Collett et al., 2015; 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 targeted for mining are located deeper within the hydrate stability zone.

A given volume of methane causes 15 to 20 times more greenhouse gas warming than the equivalent volume of carbon dioxide (Collett et al., 2015; Consortium for Ocean Leadership, 2013). However, most methane hydrates would require sustained warming over thousands of years to trigger dissociation (Collett et al., 2015; Consortium for Ocean Leadership, 2013).

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 proposed off Washington's Pacific coast. The infrastructure and production technology for gas hydrate extraction is anticipated to be similar to that for 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 described in 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 and intensity of this potential new activity.

In addition to the potential conflicts discussed below, other spatial conflicts could include shipping, dredge disposal, sand and gravel mining, and possibly military practices.

Commercial and recreational fisheries

Commercial fishers may be affected by offshore oil and gas operations that cause changes in the distribution or abundance of fishery resources, reduce the catchability of fish, preclude fishers from accessing viable fishing areas, or cause losses of or damage to equipment or vessels (Bureau of Ocean Energy Management, 2012b). Impacts will depend upon the fishery, fishing method or year, and nature of the particular structure. Structures may disturb access to fishing grounds and navigation. For deep-water oil and gas structures in the Gulf of Mexico, a safety zone may be established for vessels longer than 100 feet that extends up to 1,640 feet around each production platform. This would encompass up to approximately 198 acres of surface area per platform (Bureau of Ocean Energy Management, 2012b).

When structures are decommissioned, federal law requires that all wellheads, casings, pilings, and other obstructions are removed to a depth of at least 15 feet below the mud line or other approved depth. Therefore, the components left after decommissioning would not affect longlining, but would decrease the area allowable for trawl fishing (Bureau of Ocean Energy Management, 2012b).

The impacts to recreational fisheries are expected to be relatively minor with the potential for beneficial impacts. Species that live on the bottom around the structures may experience temporary effects during construction activities. However, fish return to the disturbed areas. Offshore platforms do have a positive effect as well, as these structures are known to aggregate pelagic and reef-associated species (Bureau of Ocean Energy Management, 2012b).

In Alaska, there has been a history of conflicts between commercial fisheries and seismic exploration vessels. Conflicts have included the loss of gear including crab pots and longlines, which could result in the exclusion vessels from normal fishing grounds to avoid this conflict. Some studies have found a temporary reduction in fisheries catch during or following seismic surveys. This could be avoided by conducting the studies during closed fishing periods (Bureau of Ocean Energy Management, 2012b). Recreational fisheries can experience disruptions to fishing ground access, lost gear, and reductions in catch following seismic surveys (Bureau of Ocean Energy Management, 2012b).

Recreation and tourism

The impacts to recreation and tourism in the Gulf of Mexico and Alaska are predicted to be either temporary or related to aesthetics. Temporary effects will primarily be experienced during construction of new facilities and could include increased noise and vessel traffic and spatial conflicts with recreational fishers. In the Gulf of Mexico, the aesthetic impacts are expected to be minor and result from increased vessel traffic and aircraft traffic. In Alaska, there would be potential adverse aesthetic impacts on sightseeing, boating, fishing, and hiking activities. The possible effects on scenic quality in Alaska include debris and trash washing up on shore (Bureau of Ocean Energy Management, 2012b).

Cultural and historic resources

Cultural and historic resources may be impacted by mining and drilling activities. Potential affected sites include historic shipwrecks and inundated prehistoric sites offshore. In many areas, the locations of most of these sites are unknown. If any are discovered during offshore activities, they are subject to archaeological surveys and other mitigation requirements. Effects on cultural resources can be determined on a case-by-case basis using project-specific surveys to identify cultural resources. If a survey finds evidence of a possible archaeological resource in a lease area, they must either move the activity or conduct further investigations. If an archaeological resource is present at a location and cannot be avoided, BOEM requires consultation with the State Historic Preservation Office to develop mitigation measures (Bureau of Ocean Energy Management, 2012b).

Permitting Gas Hydrate Mining

Gas hydrate mining in the MSP Study Area is unlikely to occur, as the average saturation level is low and other areas have more significant resources. Gas hydrates are also unlikely to occur within state waters. In addition, there is a ban in place preventing offshore oil and gas drilling in federal waters off the coast of Washington.

It is unclear at the time of writing exactly what the permitting and leasing procedures would be for gas hydrate mining in the MSP Study Area. If this were to happen in state waters, DNR would need to authorize the activity and would likely charge a royalty. Ecology would likely require a 401 Water Quality Certification, a Coastal Zone Management Act consistency determination, and review any relevant local permits that may apply under the local SMP. Federal leasing and permitting of commercial production of gas from gas hydrates would likely be handled under BOEM through the same process currently used for production of conventional oil and gas from the OCS.

Future Trends and Factors

High concentrations of gas hydrates in sand are currently the primary targets for exploration, as conventional oil and gas technology favors methane extraction from sand-dominated reservoirs. In addition, gas hydrates can occur at various saturation levels within marine sediments. The Gulf of Mexico, for example, has an estimated 50-90% gas hydrate saturation (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 of limited duration (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 orders of magnitude 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 in 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).

BOEM has produced estimates of gas hydrate resources within the Washington coastal margin. These are modeled estimates of in-place gas hydrates and do not assess technically recoverable resources (Bureau of Ocean Energy Management, 2012a). 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 the MSP Study Area is not likely to be a primary target, given the presence of methane-rich and 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 refers to the extraction of uranium from seawater for energy purposes. Deep seabed mineral resource mining is the mining of polymetallic nodules, ferromanganese crusts, and massive sulfides from the seafloor. Literature and other resources indicated that uranium extraction and deep seabed mineral mining activities are generally in the early stages of development and are not targeting Washington waters (International Seabed Authority, 2014; G. Gill, personal communication, November 20th, 2014). As a result, we determined that these potential activities are highly unlikely to occur in the MSP Study Area in the near future, and therefore are not described further within the Marine Spatial Plan.

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2.11 Climate Change

Climate change is a global phenomenon that will impact the MSP Study Area in a variety of ways. While future effects can be projected based on the best available science, the precise magnitude, duration, and frequency of those effects are not certain. In the MSP Study Area, current 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. However, 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, and the effects of 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 informed by projections from climate change models. However, both the models and expected impacts 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 component of climate, such as temperature or precipitation, which lasts for decades or longer. Historically, this change has been attributed to natural factors, but the rapid changes being observed now are primarily the result of human activities (U.S. Environmental Protection Agency, 2016a). Shifting climate has the potential to drive significant changes in the air, land, and sea that will in turn influence 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 the addition of significant amounts of greenhouse gases into the atmosphere by processes such as the burning of fossil fuels for electricity generation and transportation (U.S. Environmental Protection Agency, 2016a). 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, 2016a). 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. The extra heat trapped in the atmosphere 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

[1] Fluorinated gases are gases that contain fluorine including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (U.S. Environmental Protection Agency, 2016a).

the atmosphere by burning fossil fuels and clearing forests (U.S. Environmental Protection Agency, 2016a).

Many of the major greenhouse gases can remain in the atmosphere for tens to thousands of years after being released. 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. Greenhouse gases all mix together in the lower part of the atmosphere and are distributed globally so that 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, 2016a).

Climate Change Impacts

Increases in greenhouse gas emissions and the resulting climate change have already impacted atmospheric conditions and are projected to continue to do so. Some of these impacts are discussed below including changes in air temperature, precipitation, and air circulation patterns.

Air temperature

The annual mean temperature in the Pacific Northwest (PNW) increased by 1.3°F between 1895 and 2011. During the same time period, the frost-free season lengthened by 35 days (±6 days) (Snover, Mauger, Whitely Binder, Krosby, & Tohver, 2013). Scientists project the annual average temperature in the PNW to rise by 5.8°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). 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 (Snover et al., 2013). Scientists project an increase in the number of heavy rainfall events (Snover et al., 2013) and less snow accumulation (Climate Impacts Group, 2009).

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). More detail on ENSO and PDO is available in Section 2.1: Ecology of Washington’s Pacific Coast. Although ENSO and PDO are unique from the climate change discussed in this section, 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. A typical ENSO event will last for 6-18 months and a typical PDO event will last for 20-30 years (Moore, Mantua, Hickey, & Trainer, 2010). It can be challenging to distinguish between long-term climate change trends and climate cycles like these that occur on annual to decadal time scales. It is still unclear what impacts climate change will have on ENSO and PDO, and whether it will force changes in either frequency or intensity (I. M. Miller, Shishido, Antrim, & Bowlby, 2013; Vecchi & Wittenberg, 2010).

Ocean and Coastal Impacts

Climate change resulting from human-related increases in greenhouse gases influences many components of marine ecosystems. Increased CO_2 in the atmosphere directly causes increases in ocean temperatures and acidity (Doney et al., 2012). Increases in ocean temperatures drive additional changes including rising sea level, increased ocean stratification, decreases in 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 temperatures, dissolved oxygen, sea level rise, flooding, erosion, storms, ocean acidification, and harmful algal blooms are briefly discussed in this section.

Ocean temperatures

Ocean temperature can be broken down into two categories: 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 ocean has not warmed as much as the atmosphere, even though the ocean has absorbed a majority of the Earth's extra heat (U.S. Environmental Protection Agency, 2016a). 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 (I. M. Miller et al., 2013).

Global sea surface temperature has increased at an average rate of 0.13°F per decade between 1901 and 2015 (U.S. Environmental Protection Agency, 2016a). Mote and Salathe (2010) projected sea surface temperature increases of about 2.2°F for the coast of the Pacific Northwest in 2030-2059 compared to the 1970-1999 average annual cycle.

Changes in ocean temperature influence sea level because water expands slightly as it warms, in a process known as thermal expansion. The heat in ocean surface waters also provides energy for storms, influences weather patterns, and can change ocean currents (U.S. Environmental Protection Agency, 2016a). 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, 2016a).

Increasing sea surface temperatures could weaken the circulation patterns responsible for the upwelling of water and nutrients from the deep sea to surface waters. In turn, this may contribute to declines in fish populations which may ultimately lead to decreases in seafood supply and jobs within the fishing industry (U.S. Environmental Protection Agency, 2016a). Effects on local species are discussed in the below section on environmental impacts.

Another driver of sea surface temperature change in the MSP Study Area has been the Blob (a.k.a. North Pacific Mode or marine heat wave). In 2013-2015, the Blob resulted in surface waters 1.8°-7.2°F warmer than usual off the West Coast (Kintisch, 2015). During this time, scientists documented a decrease in copepod populations off the Oregon coast, thousands of seabird deaths, and the starvation of thousands of sea lions in California, all potentially associated with the Blob (Di Lorenzo & Mantua, 2016; Kintisch, 2015). The Blob is believed to result from natural variability and not human-caused climate change. However, the high-pressure atmospheric ridge that produced the Blob may be more likely to occur under future climate conditions, and the associated ecological effects from the Blob may provide a preview of potential future impacts from climate change (Kintisch, 2015).

Hypoxia and anoxia

Changes in climate are expected to impact the concentration of dissolved oxygen in the ocean. Hypoxia is a state of low dissolved oxygen concentrations that causes stress to aquatic animals, and anoxia occurs when there is 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. These bacteria respire and use dissolved oxygen in the process, further decreasing the amount of dissolved oxygen available in the water (I. M. Miller et al., 2013).

The Washington coast 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 increased frequency of storms that produce winds favorable to downwelling. In the summer, waters at depth have decreased 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 (I. M. 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 increased sea surface temperatures or decreased salinity (due to increasing freshwater input). The combination of these factors will reduce dissolved oxygen concentrations in subsurface waters as the deeper, denser water is less apt to mix with surface waters and experiences longer periods of respiration at depth (I. M. Miller et al., 2013).

Sea level rise and flooding

Sea level and the temperature of the Earth 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, the volume of water in the oceans will increase. Sea level rise is a threat to coastal communities through shoreline erosion, contributions to coastal flooding, and inundation of low-lying land. Higher sea levels can also threaten coastal infrastructure, as higher storm surges increase the likelihood of flooding (U.S. Environmental Protection Agency, 2016a).

Since 1993, global average sea level has risen at a rate of 0.11 to 0.14 inches per year (U.S. Environmental Protection Agency, 2016a). Global average sea level is projected to increase by 11 to 38 inches by 2100 compared to the average level for 1986-2005 (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 American Plate forces vertical land motion that can either increase or decrease the overall rate of regional sea level rise (Dalton, Mote, & Snover, 2013; I. M. Miller et al., 2013).

Absolute sea level change refers to the change in the height of the ocean surface regardless of nearby land motion. Relative sea level change is measured in reference to land elevation, which may have risen or fallen (U.S. Environmental Protection Agency, 2016b). On the Olympic Peninsula, the northwest 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 relative sea level rise (Dalton et al., 2013).

Changing wind stress patterns may also impact sea level rise along the coast.[3] Since approximately 1980, the North Pacific has been experiencing 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 shoreline characteristics and the rate of sea level rise. Higher sea level may exacerbate flooding of coastal rivers. Both the extent and depth of flood waters may increase, as it will be harder for flood waters in rivers to drain into the ocean. High river flows are also expected to increase in size and frequency due to 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 (I. M. Miller et al., 2013). Global climate models project that storm tracks in the PNW will drive northward over time and there will be an increase in the intensity of the precipitation associated with these storms. Other associated impacts are likely to include increasing wave heights and the potential for large storm surges which could increase coastal erosion (I. M. Miller et al., 2013).

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[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).

[3] Changes in atmospheric circulation can result in changes to wind stress.

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 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. In addition to the erosion occurring, sediment supply to the coast has been reduced due to the construction of mainstem dams on the Columbia River, limiting the sediment available to replenish beaches. Washington's Pacific coast has several areas of high erosion, including Washaway Beach which has the fastest erosion rate on the Pacific coast. On average, Washaway Beach has been losing 65 ft. of beach annually since the 1880s (Climate Impacts Group, 2009).[4]

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). Additional sources driving acidification in Washington include upwelling, hypoxia, and local input of nutrients, nitrogen oxides, and sulfur oxide gases. Since the mid-1700s, open ocean surface waters have become approximately 30% more acidic (Chan et al., 2016; R. Feely, Klinger, Newton, & Chadsey, 2012). By 2100, Washington's coastal waters are projected to increase in acidity by 38% to 109% compared to the average level 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 ions are required by many marine animals and some plants to build shells, skeletons, and other hard parts formed with calcium carbonate. Calcium carbonate, usually in the form of calcite or aragonite, is also susceptible to acidification as the water becomes more chemically corrosive (R. A. Feely, Doney, & Cooley, 2009; Washington State Blue Ribbon Panel on Ocean Acidification, 2012). 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 (Kroeker et al., 2013). It is also projected to cause a 17% decline in growth and a 34% decline in survival for mollusks (Kroeker et al., 2013). In general, scientific studies have found that heavily calcified organisms including calcified algae, corals, mollusks, and the larval stages of echinoderms are the most negatively impacted by ocean acidification (Kroeker et al., 2013).

[4] Attempts to mitigate erosion at Washaway Beach are discussed in Section 2.10.3: Dredging and Dredged Material Disposal.

Organisms that are not impacted by reduced calcification are still experiencing other negative consequences from ocean acidification. Some species experience decreased growth, reproductive issues, behavioral changes, and increased mortality. These negative impacts are felt throughout the ecosystem as these species 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. In some locations, more than 50% of the population of these planktonic marine snails are showing signs of shell dissolution (Bednarsek et al., 2014; Chan et al., 2016). Many West Coast fisheries species like herring, mackerel, and salmon rely on pteropods as an important food source and are therefore indirectly vulnerable to ocean acidification (Chan et al., 2016).

While the direct effects on finfish in Washington may be unknown, studies elsewhere have shown that some fish are susceptible to increasing acidification of ocean conditions. Fish have been found to experience impacts on their otoliths, bony structures that they use to sense orientation and acceleration. Fish grown in seawater with high levels of CO_2 had significantly larger otoliths than fish grown in present-day conditions (Checkley Jr. et al., 2009).

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 driven by 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 estuaries, they can combine with inputs of nutrients and organic matter and create 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 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 of concern 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 in the genus *Pseudo-nitzschia* (Climate Impacts Group, 2009; Washington State Department of Fish and Wildlife, 2015).

HABs on the Washington 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 (Climate Impacts Group, 2009). The high sea surface temperatures associated with The Blob in 2015 resulted in the largest HAB ever recorded, which stretched from southern California to southeast Alaska. The HAB caused shellfish fishery closures due to contaminated shellfish in Washington, Oregon, and California and had significant socio-economic consequences (Di Lorenzo & Mantua, 2016; Gentemann, Fewings, & Garcia-Reyes, 2017). There were also significant delays to the opening of the commercial and recreational crab fishing season along the West Coast (Gentemann et al., 2017). The HABs associated with The Blob may be a precursor of the impacts due to climate change. 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). HABs in the MSP Study Area are also related to the Juan de Fuca Eddy. The eddy serves as a source of toxic cells and blooms that can be transported to Washington's coastal waters by currents, winds, and shifts in upwelling and downwelling trends (Trainer et al., 2009; Trainer, Hickey, & Horner, 2002). Climate change impacts on factors including winds can impact the frequency or transport of blooms from the eddy to the coastal waters of the MSP Study Area.

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 the structure and functions of an ecosystem (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 (I. M. Miller et al., 2013).

Another result of changes to the physical environment may be changes in the phenology of organisms. Changes to the physical environment may drive changes to the seasonal timing of certain phases of organisms' life cycles (I. M. Miller et al., 2013; Poloczanska et al., 2016). These shifts in life cycles will not only impact the organisms themselves, but may alter predator and prey relationships and lead to larger changes at the ecosystem scale (Brander, 2010). Scientists have already documented shifts in timing of phytoplankton blooms, which can impact organisms up the food web (Edwards & Richardson, 2004). Organisms at higher trophic levels, such as migrating juvenile salmon, are highly dependent on phytoplankton blooms and often rely on them during certain stages in their life cycle (Doney et al., 2012).

These changes in timing have previously caused negative impacts in the MSP Study Area. In 2005, a delay in the start of upwelling in the PNW caused a delay in phytoplankton production (Schwing et al., 2006). Associated impacts were low survival of some salmon species, recruitment failure of many rockfish species, and nesting failure and mortality in seabirds (Peterson & Schwing, 2008). Intertidal invertebrates like barnacles and mussels also showed unprecedented low recruitment during the early upwelling season, which could have consequences for predators higher in the food web (Barth et al., 2007).

Species shift the areas in which they live, also referred to as their range, as climate and local conditions change (Pinsky, Worm, Fogarty, Sarmiento, & Levin, 2013; Poloczanska et al., 2016). If conditions become too extreme, some species will be able to shift to locations with more favorable conditions. Studies have documented shifts in species ranges due to changes in temperature. Fish species have been documented to respond to warming ocean temperatures by moving north to cooler waters or moving to deeper waters (Perry, Low, Ellis, & Reynolds, 2005). During the warm waters conditions associated with the Blob in 2013-2014, dramatic range shifts of a variety of fish species were reported off the West Coast, Alaska, and British Columbia. This included unusual distributions of juvenile salmon in Alaska and more northerly sockeye returns in BC (Bond, Cronin, Freeland, & Mantua, 2015). 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 (I. M. Miller et al., 2013; Poloczanska et al., 2016).

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. Changes in climate will be experienced in different ways on the steep rocky shores of the coast north of Point Grenville, along the sandy beaches with shallow slopes and high energy waves south of Point Grenville, and in the estuaries, which have 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.[5]

Pelagic habitats

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 (I. M. Miller et al., 2013). Increasing surface water temperatures may increase stratification in the water column and, therefore, decrease primary productivity by reducing mixing with nutrient-rich waters (King et al., 2011). However, increases in upwelling winds could increase mixing and counteract the stratification (King et al., 2011). Shifts in primary productivity related to changes in upwelling can impact the entire food web. Some plankton that need calcium carbonate to build their shells, like larval oysters and pteropods, will experience negative impacts from ocean acidification. Other plankton like euphausiids may benefit from increasing water temperatures (I. M. Miller et al., 2013).

Copepod communities have also been impacted by increasing water temperatures. Cold water “northern” copepod species are lipid-rich and therefore a good food source for fish. Warm water “southern” copepod species are lipid-poor and provide a poor food source for small fish, which are then prey for juvenile salmon. As water temperatures increased on the Oregon shelf in 2015-2016, the zooplankton community was observed to be dominated by warm water copepod species (McClatchie et al., 2016). This has the potential to have a negative impact on the fish species relying on copepods for food, and further impacts on the food web.

Pelagic fish 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 prey availability will impact

[5] More information on the habitats discussed here are available in Section 2.1: Ecology of Washington’s Pacific Coast.

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 fish (I. M. Miller et al., 2013). Pelagic fish are also expected to shift their ranges in response to increasing ocean temperatures, and local fish communities will shift toward warm water species. In turn, this could lead to shifts in commercial fishery catch compositions and shifts in fishing grounds (Cheung, Brodeur, Okey, & Pauly, 2015).

Seafloor habitats

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 found in the MSP Study Area may be especially impacted by changes in water temperature and acidification, as they use aragonite to form their skeletons (I. M. Miller et al., 2013; Skewgar & Pearson, 2011). Any decline in the quality or extent of deep-sea coral ecosystems would have an impact on the many species of fish and invertebrates that utilize them for habitat (I. M. Miller et al., 2013; Skewgar & Pearson, 2011). The seafloor is also habitat for many shellfish species that are likely to be harmed through slower growth rates, thinner shells, and higher mortality rates caused by climate change and ocean acidification (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). Commercially significant impacts are discussed in the fisheries section below.

Deep-water fish may suffer losses of suitable habitat and decreased populations if hypoxic or anoxic zones expand, or if the frequency of events increases (Koslow, Goericke, Lara-Lopez, & Watson, 2011). 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 (Ainsworth et al., 2011). For example, modeling for cumulative impacts of fishing effects and ocean acidification impacts found declines of up to 20-80% in abundance of commercially important groundfish including English Sole, Arrowtooth Flounder, and Yellowtail Rockfish. These declines are attributed to the loss of shelled prey items from their diet as a result of ocean acidification (Kaplan, Levin, Burden, & Fulton, 2010).

Kelp forests

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 from ocean acidification, as an increase in available CO_2 could benefit their productivity. There is even work underway in Puget Sound to study whether large, healthy kelp forests could mitigate increases in CO_2 by absorbing the extra input (Hance, 2016). However, it is unclear if the benefits of increasing CO_2 would exceed any of the consequences caused by increasing ocean temperatures (I. M. Miller et al., 2013).

Increasing storm intensity has the potential to impact kelp forest habitats by shifting the availability of large hard substrates needed for attachment and by damaging seagrasses through wave action (Byrnes et al., 2011; Cavanaugh, Siegel, Reed, & Dennison, 2011; Ebeling, Laur, &

Rowley, 1985). Increases in the frequency and intensity of storms also decrease the diversity and complexity of kelp forest food webs (Byrnes et al., 2011).

Rocky shores

Climate change is likely to cause stress to intertidal organisms that have limited vertical ranges. Stresses include those from heat and exposure above, and from predators below. The suitable ranges for these organisms may get even narrower as higher air temperatures force them lower into the intertidal zone, and as some predators become able to move higher into the intertidal zone due to sea level rise (I. M. Miller et al., 2013). 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 due to their 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 (I. M. Miller et al., 2013).

The ochre sea star, a keystone predator in the rocky shores, has suffered from sea star wasting disease (SSWD) in recent years. Sea stars have experienced high mortality rates, which scientists have tied to the spread of densovirus. The high rates of disease progression and mortality have been linked to warm temperature anomalies (Eisenlord et al., 2016), leading to concerns about potential recurrences due to climate change impacts.

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. This habitat may be lost if erosion causes beach areas to coarsen and steepen due to increasing erosion, storm intensity and storm frequency (I. M. Miller et al., 2013). The impacts of storm surges and high waves on the coast will be magnified by sea level rise, and the net result of storms and sea level rise is coastline retreat (National Research Council, 2012).

Large coastal estuaries

Many of the key factors that drive the functioning of estuaries are affected by climate change. Changes in 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 the climate changes (Skewgar & Pearson, 2011). Reductions in estuarine habitats like tidal flats, coastal wetlands, and beaches will impact associated animals like forage fish and shorebirds (Dalton et al., 2013).

Some of the plant and animal life dependent on estuaries, such as wild and farmed shellfish, will be harmed by acidifying waters. Other habitat-forming species, such as eelgrass and kelp, will potentially experience good conditions for growth such as increases in temperature and CO_2, but poor conditions related to increased storm events and 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 (I. M. 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 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.

State and tribal fisheries

Climate change and the associated changes in 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, clams, oysters, 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 testing more acidic ocean conditions, crab larvae experienced lower survival and slower development (J. J. Miller, Maher, Bohaboy, Friedman, & McElhany, 2016) and juvenile crab experience higher mortality (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). The availability of these organisms for harvest may also be reduced if harmful algal blooms become more prevalent.

Ocean acidification impacts not only 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 (Bednarsek et al., 2014; 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 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 due to 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). Research in the northeastern U.S. shows a variety of impacts of increasing ocean temperatures on fisheries in the area. Researchers found that northward shifts in species distributions were matched by corresponding northward shifts in fisheries. However, fisheries shifted only 10-30% as much as their target species. They also found that the proportion of warm-water species caught in most states also increased through time (Pinsky & Fogarty, 2012).

In the short term, travel time and costs for fishermen may increase as fishing grounds shift. In the long term, there may be increased costs and challenges for fishermen and the fishing industry, such as those associated with adapting gear and infrastructure to harvest and process new species (Pinsky & Fogarty, 2012).

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 Washington 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 losses 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. Recreational shellfish fisheries have 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, resulting in negative economic consequences (Dyson & Huppert, 2010). As discussed above, in 2015 the largest HAB ever recorded caused shellfish fishery closures due to contaminated shellfish in Washington, Oregon, and California (Di Lorenzo & Mantua, 2016; Gentemann et al., 2017).

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 organisms' ability to form, build, and maintain their shells. Shellfish farmers are already experiencing increased costs as they deal with acidifying coastal waters and associated increases in larval oyster mortality (Washington State Blue Ribbon Panel on Ocean Acidification, 2012).

Shellfish farmers have adapted hatchery operations to try to avoid issues by monitoring water conditions and changing the time that they draw water into the hatcheries. Some have developed hatchery operations in Hawaii, where the water is less corrosive. These hatcheries raise larvae until they're big enough to tolerate the conditions in Washington (The Columbian, 2013).

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 potential for commercial shellfish operations to 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 adaptation may be required to maintain full functioning of the facilities. The transportation systems that surround and support ports may also experience negative consequences to their infrastructure that impact 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, requiring additional effort and expenditures by the port (Industrial Economics Inc., 2014b).

Tribal uses

Projected climate change impacts discussed throughout this section threaten tribal lands, resources, economies, homelands, ceremonial sites, burial sites, traditions, and cultural practices (Dalton et al., 2013). Tribal economies, traditions, and treaties are heavily reliant on place-based natural resources, which makes them disproportionately susceptible to the negative consequences of climate change (P. Mote, 2015). Tribal members rely on the marine ecosystem of the MSP Study Area for food, employment, and cultural, social, and health benefits (Northwest Indian Fisheries Commission, 2016).

Climate change impacts on the environment threaten the loss of traditional resources from historical and established fishing, gathering, and hunting areas (Northwest Indian Fisheries Commission, 2016). Shifts in species distribution may move important resources to areas that where tribes no longer have access, either physically or legally (Dalton et al., 2013). Warming ocean temperatures can cause salmonids and other animals to alter their ranges, potentially shifting them out of areas available to the tribes (Northwest Indian Fisheries Commission, 2016).

Climate change issues related to sea level rise, heavy rain events, and peak stream flows may potentially damage tribal infrastructure. Residences, historical sites, and community and government buildings are all vulnerable. Economic impacts could result from damage to infrastructure (Northwest Indian Fisheries Commission, 2016). Some tribes may lose part of their reservations due to inundation along the coast (Dalton et al., 2013).

In a study conducted through interviews with members of three Northwest tribes (Quinault Indian Nation, Confederated Tribes of Salish and Kootenai, and Confederated Tribes of Siletz Indians), 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. A cue based on weather, plants, or animals would signal the beginning of a new season or the appropriate timing of an event or tradition. It can be challenging to rely on traditionally-held information about environmental factors that influence cultural activities as they change. 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).

Tribes are engaged in climate assessments, adaptation and mitigation planning, research, monitoring, outreach, and education. Many tribes in the PNW have been engaged in or are beginning to consider climate change adaptation planning to address potential impacts on tribal culture, resources, and economies. Tribes are also engaged in research and monitoring and often partner with universities, agencies, and other entities (Dalton et al., 2013).

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 their 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, 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). One grower has moved hatchery operations to Hawaii to avoid the impacts of ocean acidification on oyster larvae. The associated costs are obviously great and not all growers will have the means to relocate hatcheries. Growers that do not own a hatchery but instead purchase oyster spat 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 available harvest time and reduce workdays for growers (Taylor et al., 2015). In addition to the aquaculture industry, ocean acidification threatens recreational shellfish harvesting and the economic benefits it 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).

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 changes in the local economy of Pacific and Grays Harbor Counties due to reduced visitor expenditures during recreational shellfish fishery closures due to HABs. They found a single beach closure for an average opening (typically 2-5 days) of all beaches to be associated with an expenditure reduction of $4 million dollars (2008 dollars). The authors found a whole season closure (October through April) to be associated with an expenditure reduction of $20.4 million dollars (2008 dollars) (Dyson & Huppert, 2010). 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 other ways. However, this 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 due to climate change. However, the specific effects are challenging to assess 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). Shellfish, such as Dungeness Crab and Pink Shrimp, are 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. A study of the impacts of ocean acidification on California Current fisheries projects that Dungeness Crab will suffer a 30% decline in biomass and catch by the year 2063 (Marshall et al., 2017). 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. Interactions between these stressors and their cumulative impacts add to the complexity of understanding and adapting to climate change. The physical environment, plant and animal life, human communities, economies, and existing uses of the MSP Study Area are all likely to experience changes as climate shifts.

As climate change continues and the impacts are felt throughout the MSP Study Area and beyond, demand for the new ocean uses addressed in this MSP may be affected. 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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