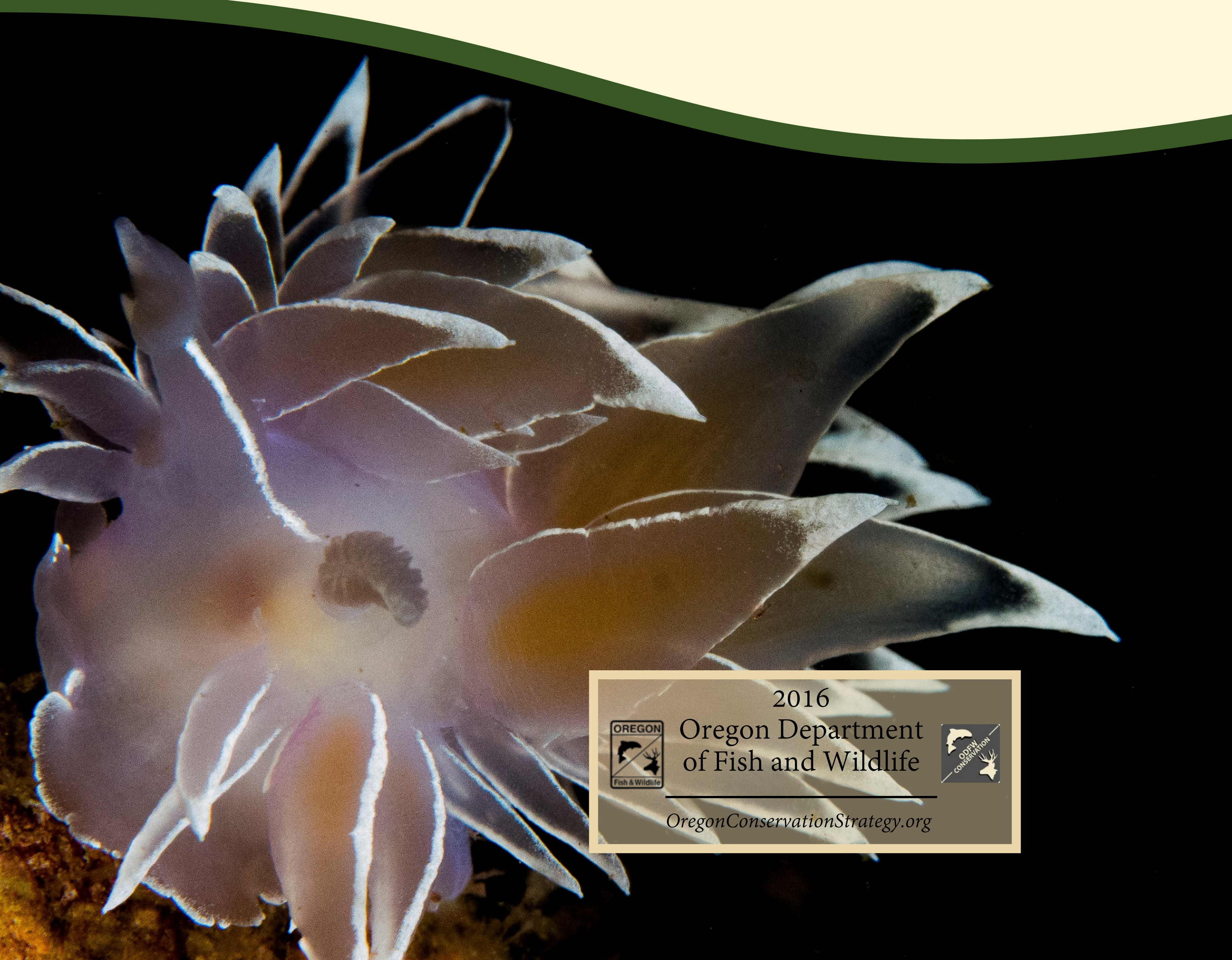



the OREGON NEARSHORE STRATEGY




Appendices



2016
Oregon Department of Fish and Wildlife
OregonConservationStrategy.org

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PDF Content Last Updated January 3, 2017

The Oregon Nearshore Strategy is the marine component of the official State Wildlife Action Plan for Oregon. The complete Oregon Conservation Strategy is available online at http://oregonconservationstrategy.org/. Since Conservation Strategy content will be updated periodically, please check the website to ensure that you are using the most current version of downloadable files. What are now Appendices A – D of the 2016 Nearshore Strategy were first posted on the ODFW website in 2012. What is now Appendix G is a revised and updated version of the list of non-native and invasive species initially compiled in 2012. Funding for the project completed in 2012 was through the Oregon Department of Fish and Wildlife and the Wildlife State Grant Program grant T-31-P-1 in cooperation the U.S. Fish and Wildlife Service and Sport Fish Restoration Program. The ODFW Nearshore Team who worked on that project included Allison Dauble, Delia Kelly and Gregory Krutzikowsky. Note that the definition of Oregon's Nearshore was changed as part of the update to the 2016 Nearshore Strategy which is apparent in reading Appendices A - D, but the potential impacts and effects of global climate change and ocean acidification, as well as the information about non-native and invasive species presented in these appendices remain relevant throughout the redefined borders of the Nearshore. Indeed, the work in 2012 anticipated the inclusion of estuaries as part of the Nearshore which is apparent in Appendix G. Appendices E and F present updated information on the revised Watch List and Other/Commonly Associated Species List, respectively.

Recommended Citation

Oregon Nearshore Strategy. 2016. Oregon Department of Fish and Wildlife, Salem, Oregon.

Cover Photos

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TECHNICAL SUPPLEMENT

The Oregon Conservation Strategy: Potential Impacts of Global Climate Change in Oregon's Nearshore Ocean

Introduction

Global atmospheric concentrations of carbon dioxide, the dominant greenhouse gas, have increased markedly since 1750 and now far exceed pre-industrial values[1]. The Intergovernmental Panel on Climate Change, an international working group of several thousand scientists, found that the Earth's climate is warming as a result of this increase in carbon dioxide concentrations[1]. The rapid increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea levels observed over the last century are evidence of these climatic changes[1]. A large portion of the carbon dioxide in the Earth's atmosphere is absorbed by the world's oceans[2,3]. Oceanic absorption of carbon dioxide temporarily slows atmospheric accumulation and its effect on climate[4]. This uptake of carbon dioxide changes the chemical equilibrium of seawater, making the oceans more acidic[1]. Evidence from all continents and almost all oceans show that many natural ecosystems are being affected by these impacts of increased carbon dioxide concentrations[1].

Impacts on the marine environment include, but are not limited to, increasing ocean temperatures, sea level rise, changing circulation and weather patterns, and changes in ocean chemistry[5]. Due to the complexity of the ocean and the relative scarcity of long-term or large-scale studies, the specific processes through which a changing climate will impact Oregon's nearshore are not entirely clear[6]. Scaling global climate change impacts to a local level can be problematic. Directly attributing changes observed locally to increased global carbon dioxide concentrations may be difficult[2]. Nevertheless, the significance of these potential impacts, especially along the dynamic Oregon coast[6], provides focus for scientific research efforts to document their effects.

Managing for a Changing Marine Environment

Sustainable resource management in a rapidly changing climate requires proactive planning for mitigation and adaptation at multiple scales. Physical and chemical changes are occurring in all habitats[1] and will affect local fish and wildlife resources[7] managed by the State of Oregon. Given that climate change is a complex and controversial issue, federally approved state wildlife action plans are useful platforms to guide statewide and regional planning efforts[8]. The Oregon Conservation Strategy[9] and its marine component the Oregon Nearshore Strategy[10] form the blueprint for the conservation of Oregon's fish, wildlife, and their habitats.

The Oregon Nearshore Strategy focuses on species and habitats in Oregon's nearshore marine environment[10]. Preparing for these impacts of a changing climate on Oregon's ecosystems is imperative[11]. Scientific information is available to guide initial planning efforts. This document, as a technical supplement to the Oregon Nearshore Strategy, synthesizes relevant information on Oregon's changing ocean. This information is intended to:

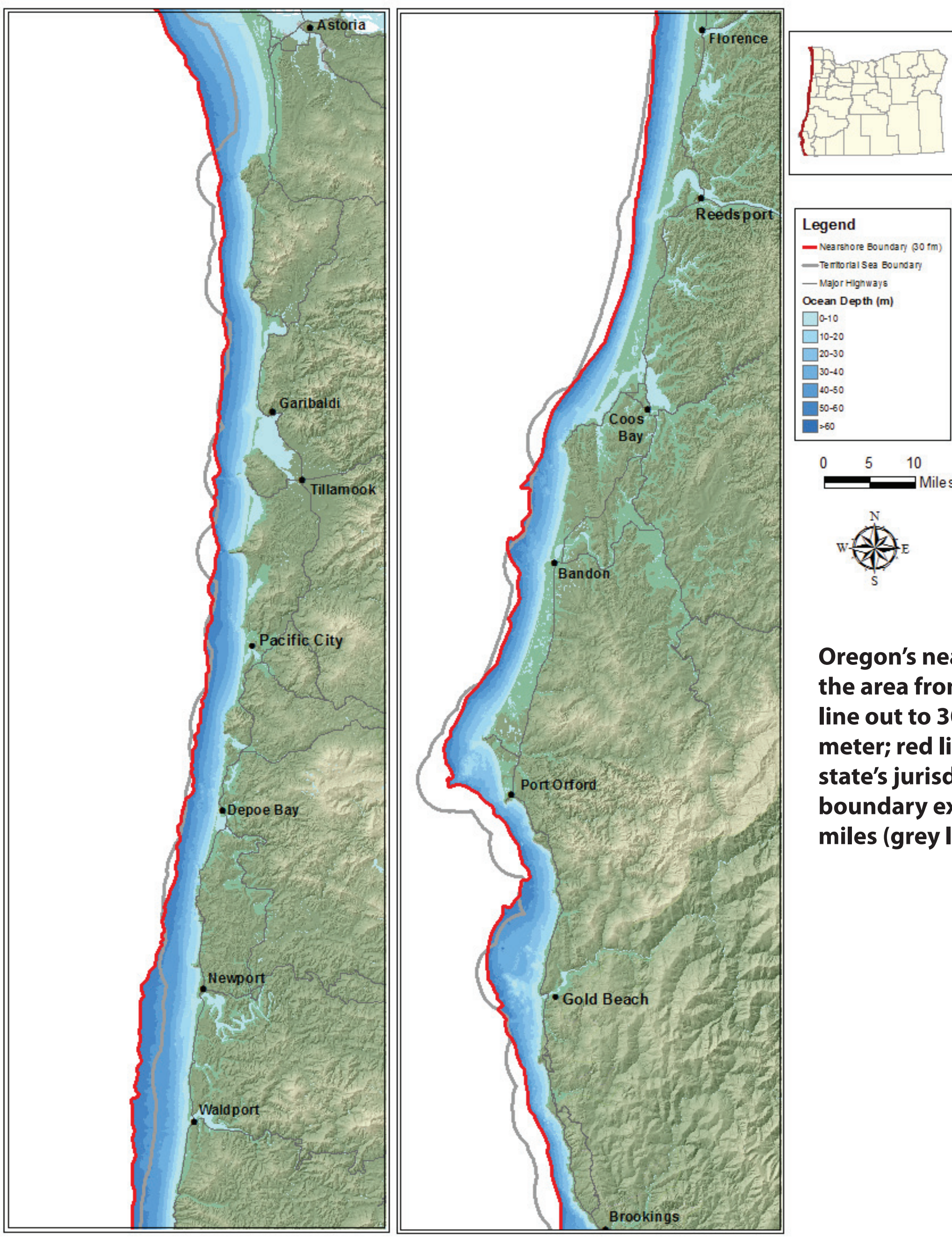
- Provide insight into potential impacts of a changing marine environment on Oregon's nearshore marine habitats and species;
- Guide future investigations and monitoring efforts in Oregon's nearshore environment; and
- Provide information and guidance for future refinement of the Oregon Nearshore Strategy.

Oregon's Nearshore Marine Environment

Oregon's nearshore marine environment encompasses the area between the coastal high tide line offshore to the 30 fathom (180 feet or 55 meter) depth contour[10] (Figure 1). This area includes a variety of habitats and a vast array of fish, invertebrates, marine mammals, birds, algae, plants and micro-organisms[10]. The sandy beaches and rocky areas located between extreme high and low tides are the intertidal zone that links subtidal habitats and offshore marine waters to the terrestrial environment[10]. Oregon's nearshore subtidal habitats include all rocky and soft bottom areas below the low tide line to the 30-fathom depth contour[10]. Nearshore pelagic or open water habitats out to 30 fathoms are part of the ocean's neritic zone that extends beyond the nearshore out to approximately 650 feet (200 meters).

Many factors, including light, temperature, storms, circulation, currents, freshwater input, and offshore conditions affect Oregon's nearshore habitats and the species living there[10]. More than 40 estuaries and tidal creeks[6], including the influential Columbia River estuary, link the terrestrial environment to Oregon's

Figure 1: Oregon's Nearshore Ocean



Oregon's nearshore is defined as the area from the coastal high tide line out to 30 fathom (180 feet or 55 meter; red line) depth contour. The state's jurisdictional territorial sea boundary extends to three nautical miles (grey line).

marine waters. Nearshore habitats are connected to the offshore continental shelf and are affected by both local environmental forces and changes occurring elsewhere in the Pacific, primarily through linkages with the dynamic offshore waters of the California Current. Species in Oregon's nearshore respond to changes in their habitats in various ways. All of these habitats and species are integral parts of Oregon's complex nearshore ecosystem, and are interconnected through a multitude of biological, physical, and chemical factors that will be impacted by global climate changes.

Cyclic Patterns and Climatic Variability in Oregon's Nearshore

Oceans exhibit patterns and variability over a range of spatial and temporal scales. Ocean and climatic conditions are tightly linked, which influences the organisms that inhabit the marine environment[5]. Annual and interannual climatic patterns tend to be most variable in the nearshore and are highly responsive to a wide variety of physical drivers[6]. Patterns influencing Oregon's nearshore ocean include processes such as upwelling and downwelling processes, the El Niño Southern Oscillation, and the Pacific Decadal Oscillation.

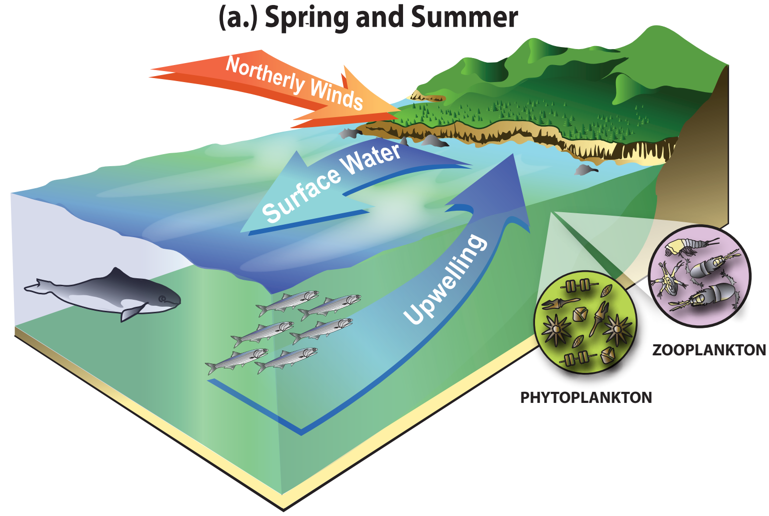
Upwelling/Downwelling: A large portion of the variability of Oregon's nearshore is closely related to local annual wind patterns[6], which exert drag on the surface of the ocean. The combination of the Earth's rotation and the dynamics of transferring the wind's energy downward into the water column results in net movement of the ocean's surface layer in a direction perpendicular to the wind. In the northern hemisphere, surface water moves 90 degrees to the right. Off the Oregon coast, when spring/summer northerly winds move surface waters away from shore, they are replaced by waters from depth in a process called upwelling (Figure 2a). Typically, this upwelled water is nutrient rich and supports strong productivity in the spring and summer.

Conversely, when fall/winter southerly winds move water towards shore, surface waters are pushed downward in a process called downwelling (Figure 2b). The transition from the fall/winter downwelling regime to the spring/summer upwelling period is called the spring transition, as it usually occurs in early spring. The winds that drive upwelling go through phases of acceleration and relaxation, and during relaxation periods, offshore waters bring planktonic food and

Figure 2. Upwelling and Downwelling

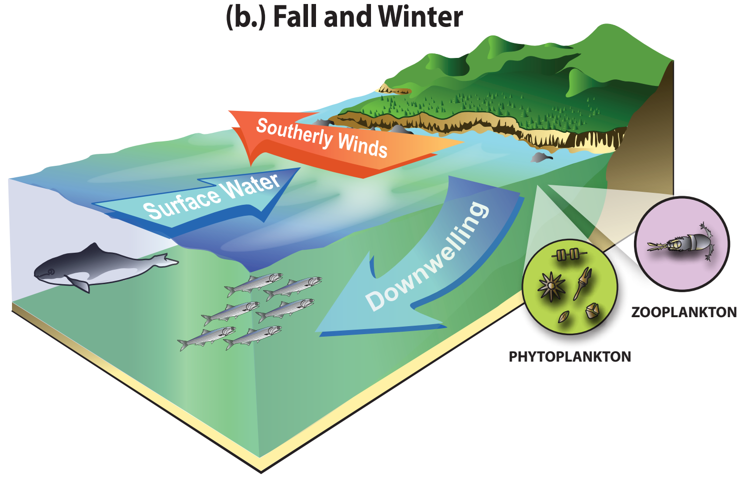
Spring and summer winds from the north move surface waters offshore. Surface waters move perpendicular to wind direction due the combined effects of earth's rotation and energy transfer downward through the water column. Surface waters are replaced by cold, nutrient rich, low oxygen waters from the deep offshore ocean in a process called upwelling. Production of nearshore plants and animals is highest during spring/summer upwelling.

(a.) Spring and Summer



Fall and winter winds from the south drive surface waters shoreward where they submerge in a process called downwelling. Downwelling transports nearshore surface waters to resupply deep offshore waters with oxygen. Storm activity is highest, and runoff from precipitation over land contributes to mixing nearshore waters and loading the environment with oxygen and freshwater inputs.

(b.) Fall and Winter



larvae into the nearshore. During upwelling surges, plankton is carried offshore and distributed along the coast. Both upwelling and downwelling events are important to maintaining the base of the marine food web, and this dynamic may become out of balance as ocean conditions become less predictable.

El Niño Southern Oscillation: Physical changes to Oregon's marine habitats on interannual scales include the ocean surface temperature changes associated with El Niño Southern Oscillation (ENSO) events, an irregular tropical cycle with connections to the Oregon coast. The tropical Pacific typically displays a large gradient in sea surface temperature, with a warm pool in the west and cooler temperatures along the equator in the east. Periodically, this warm pool surges eastward towards the American continents. These ENSO events, which include coupled El Niño and La Niña conditions, typically occur over a period of three to seven years with anomalous conditions persisting for six to 12 months at a time[12]. El Niño conditions along Oregon's coastline are characterized by the influx of warm tropical waters at the surface[12]. Severe El Niño events may move the colder and nutrient rich water deeper by as much as 165 feet (50 meters), affecting the quality of upwelled water in the nearshore and limiting nutrients brought to the surface[12]. La Niña conditions include cooler ocean surface temperatures off the Oregon coast, and generally exhibit smaller changes in the water properties[12,13]. This variability affects primary productivity, species distribution and abundances, and can drastically alter marine food web dynamics in Oregon's nearshore[12].

Pacific Decadal Oscillation: The Pacific Decadal Oscillation (PDO)[14] is considered the dominant driver of interdecadal (~20 – 30 years) variability in the North Pacific[15]. PDO is responsible for long-term changes that manifest in the California Current as changes in temperature and large-scale horizontal movement of water[16,17]. In general, the PDO alternates between two distinct phases[14]. During a positive phase of PDO, downwelling conditions off the west coast are prominent, leading to a transport of warm surface water northward from offshore California and toward the Pacific Northwest coast,whereas during the negative phase, upwelling conditions prevail and colder water is pulled southward[14,16,17]. This large-scale oceanic variability results in changes in species abundances, compositions, and distributions, and translates to impacts on the survival and distribution of salmonids[14] and multiple other marine fishes[18].

Many of these processes are controlled in part by physical climatic conditions and are altered as the Earth's climate changes due to increases in atmospheric carbon dioxide concentrations[6]. These sources of variability also interact with each other to produce additive or modulating effects over multiple time scales. Climatic variability introduces added complexity and makes it difficult to predict the consequences of a changing climate. However, the observed effects of climatic variability offer insight into how Oregon's dynamic nearshore ecosystem might respond to a changing climate.

Impacts from a Changing Marine Environment on Strategy Habitats and Species

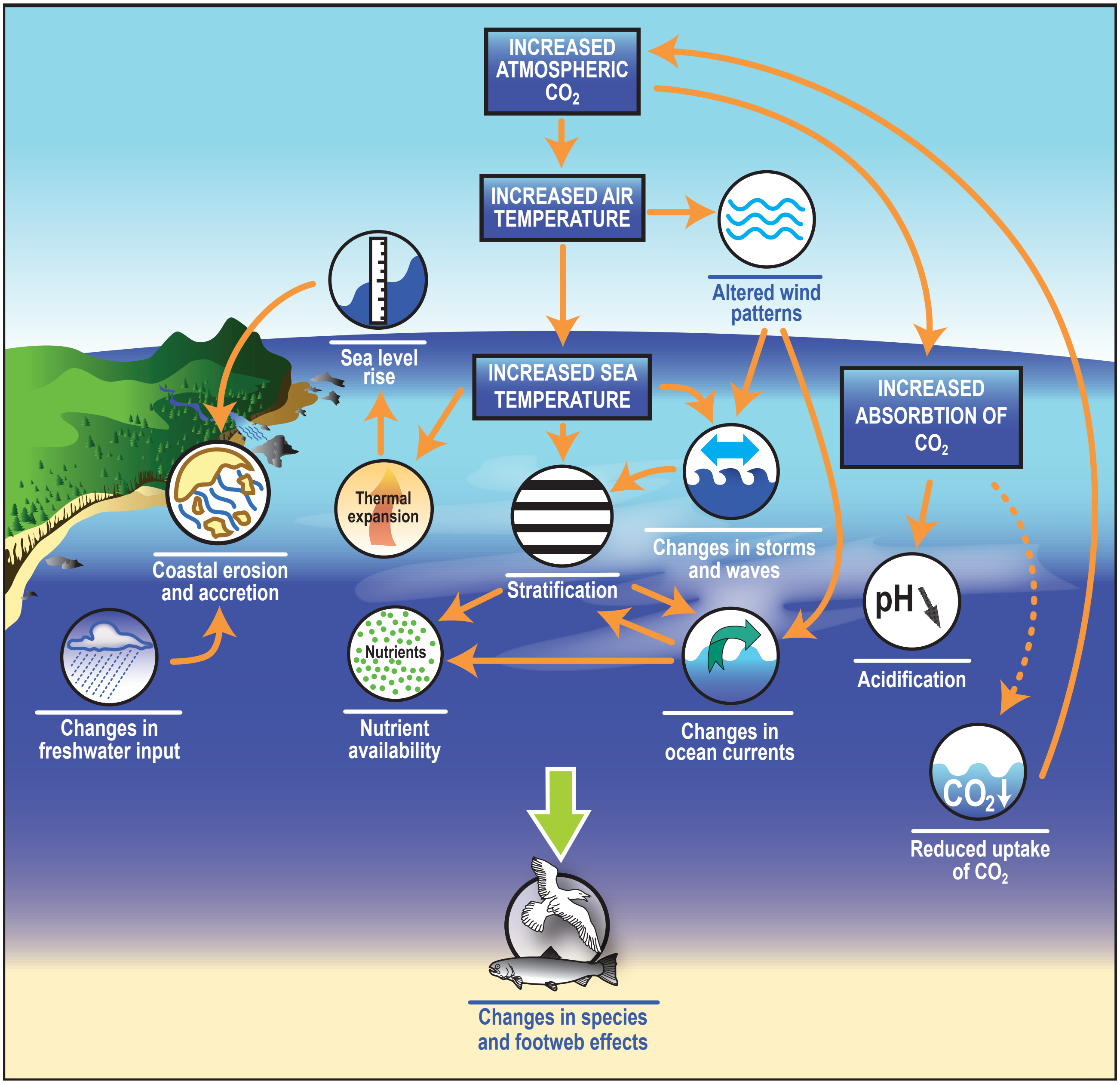
Understanding how atmospheric carbon dioxide concentrations may impact the marine environment has lagged behind that of terrestrial ecosystems[3]. No long-term (> 50 years) oceanic datasets off the Oregon coast exist and there are still many unanswered questions regarding how these effects will play out at the regional and local levels[11]. Despite the uncertainty, it is clear that Oregon's nearshore habitats and species are already experiencing changes consistent with the predicted effects of increased concentrations of atmospheric carbon dioxide[6] (Figure 3).

Changing Ocean Temperatures

The world's oceans are the main reservoir for heat energy retained in the Earth's atmosphere[2,19]. As atmospheric temperatures increase, over 90 percent of the added heat energy is absorbed by the ocean[2]. Most heat is stored in the upper water column[20]. During the latter half of the 20th century, average ocean temperatures have risen 0.2° F (0.1° C) in the

Figure 3: Oceanic Impacts of Increased Atmospheric Carbon Dioxide

The world's oceans are essential to regulating global climate, which is changing rapidly as carbon dioxide concentrations build in the atmosphere. As seen in this diagram, these impacts can interact and influence each other. Understanding the complexities of these impacts will inform managers attempting to address the impacts of a changing marine environment.



upper layers of the global ocean[2]. Oregon's coastal surface waters (< ~650 feet or 200 meters) have warmed an average of 0.5° F (0.3° C) per decade over this time period and are predicted to increase by approximately an additional 2.2 ° F (1.2° C) by the mid-21st century[6]. This estimate may be conservative, as observations over recent decades show that summertime water temperature increases have exceeded predictions[6].

Water temperature is a key factor in determining the strength of mixing in the nearshore, with higher temperatures inhibiting mixing because stratified layers of warm surface waters mix less easily with colder, deeper water. As the climate warms, the upper ocean will almost certainly be more stratified on average[21]. The thermocline (the relatively distinct layer of steep temperature gradient) is 32 – 65 feet (10 – 20 meters) deeper off Oregon in the early 21st century, compared with the middle of the 20th century[22].

Stronger stratification will make ocean mixing due to wind patterns less effective at bringing nutrients to the surface, thereby reducing primary productivity[3,21]. Increased stratification of nearshore waters may be partially mitigated[21] by predicted increases in the northerly winds that cause coastal upwelling off the Oregon coast[23].

Warming temperatures have a direct impact on the degree of environmental stress that organisms are subject to[24]. Some organisms respond by relocating to microhabitats with preferred conditions. For many immobile intertidal organisms, increased exposure and thermal stress may limit the range of suitable habitat or may reduce local populations[12,24]. Some species, such as the California mussel (*Mytilus califorinus*), grow larger or faster due to an accelerated metabolic response to warmer water temperatures[24]. In turn, this can alter competition and predation dynamics, changing the flow of energy through the food web and the structure of the ecosystem[24].

Warming ocean temperatures appear to be causing a northward shift in the distribution of fish and other mobile animals, likely associated with species-specific temperature requirements[25,26]. Poleward movement of marine fishes may actually increase species richness at temperate latitudes (e.g. the North Sea[26,27]). Species exhibiting these shifts or range expansions tend to be smaller[26,27], which will change the energy flow through the food web and alter the dynamics of the ecosystem[27]. Poleward population shifts may also be linked to temperature-associated food source availability[25]. Some fish species exhibit enhanced growth and survival when cool water zooplankton is available because this food base provides greater biomass and higher energy content[25]. Warming trends may be facilitating the ongoing range expansion of the Humboldt squid (*Dosidicus gigas*), an opportunistic predator with high consumption rates whose diet includes many commercially fished species[28].

Sea Level Rise

Global sea level is rising at an approximate rate of 0.07± 0.02 inches (1.8 ± 0.5 millimeters) per year, though this rate varies by region[2]. In the Pacific Northwest, the regional rate of sea level rise has been estimated to be slightly higher than the global average, at 0.1 inches (2.3 millimeters) per year during the 20th century[29]. Sea surface elevation rises when seawater expands as a result of increasing ocean temperatures and when land ice melts, increasing the amount of water in the ocean[2,20]. The thermal expansion of seawater currently contributes more to sea level rise than glacier and ice caps melting[20].

As sea level rises, the high-tide line migrates inland, increasing the potential for inundation, erosion, or other impacts to intertidal habitats. In Oregon, shoreline characteristics and elevation vary between steep hard substrate areas with low erosion potential to flat sandy dunes that could wash out easily as sea levels rise. Due to the variable rate of uplift on the Oregon coast, some areas may experience severe impacts sooner than others[29]. However, the projected acceleration in the rate of sea level rise will exceed all rates of uplift along the Oregon coast by the mid-21st century[29], affecting the entire Oregon coast. Natural climate variability can also affect sea levels during El Niño events[30] and during seasonal extreme high water levels occurring in the winter[31]. These combined effects on sea levels are projected to increase future coastal flooding and erosion of shoreline habitats[31,32].

Rising sea levels in rocky intertidal habitats may dramatically alter species interactions such as competition, predation, and reproduction[24]. For example, the upper range of the California mussel, a habitat engineer, continues to expand upwards in rocky shore elevation, competing with other attached invertebrates[24]. The vertical range of a keystone predator, the ochre sea star (*Pisaster ochreceus*), is also expanding with sea level rise, likely increasing predation rates on sessile intertidal invertebrates[24]. The spatial extent of intertidal sandy beaches will be reduced as sea levels rise, due to restricted inland migration imposed by coastal development and anthropogenic alteration of sediment dynamics[33]. Altered shorelines are subject to drastic increases in sand loss during large storm events, thus compounding the effects of sea level rise in sandy habitats[34]. Shoreline armoring and coastal development has been shown to reduce the ability of sandy beaches to respond to sea level rise through typical sediment dynamics[35]. The combined effects of sea level rise and coastal development on intertidal habitats will include impacts such as a reduction in the amount of spawning habitat available to species like surf smelt (*Hypomesus pretiosus*) and Pacific sandlance (*Ammodytes hexapterus*)[36].

Changes in Cycles

Oregon's nearshore ocean conditions vary on multiple time scales and to differing degrees. While some of these cycles are relatively well understood, for example, the annual cycle of upwelling and downwelling events, some, like the Pacific Decadal Oscillation[14], have only been described within the last 20 years. Understanding the underlying mechanisms responsible for these cycles is a necessary first step in understanding how they may be altered due to climate change[12]. Natural climate variability can change the biological and ecological characteristics of the nearshore, and these changes may offer clues to how habitats and species will react to a changing climate.

Annual Cycles: Increasing atmospheric carbon dioxide concentrations raise air temperatures over land more than over the ocean, leading to a greater pressure differential[23]. As a result, alongshore winds parallel to the coast could increase, which would intensify upwelling[23]. Within the California Current region, observations show that wind-driven upwelling has intensified over the last 30 years[37]. Multiple datasets off the Oregon coast indicate that summer upwelling is intensifying, particularly on the southern Oregon coast[6]. Upwelling intensification may lead to increased primary productivity though a greater delivery of nutrients to the nearshore[37]. However, this intensification could be offset by increased ocean stratification, potentially limiting the delivery of nutrients to the surface through wind-driven mixing[3,21]. The nearshore-offshore gradients in water temperature could become more pronounced as offshore waters warm and nearshore upwelling strength increases, creating stronger upwelling fronts that may impact distribution and abundances of marine organisms[21].

As a consequence of climate change, the timing of the spring transition could be delayed and followed by stronger upwelling effects later in the season[37,38]. The variability in wind stress has increased off the Oregon coast[6], leading to greater inconsistencies in upwelling patterns throughout the season. The intermittent wind relaxation periods may become less frequent, resulting in reduced transport of organisms and food into the nearshore[37]. Intensified coastal upwelling may enrich nearshore primary production of marine algae and phytoplankton[21,37] and could impact the marine food web through changes in species abundance and composition[21]. When the spring transition is delayed, primary production is also postponed[38]. Low levels of primary productivity early in the season, or delayed delivery of planktonic food sources, may lead to low recruitment of many organisms for which food availability is time-sensitive[21,38]. Planktonic fish and invertebrate larvae that are transported within the upwelling cycle may not reach inshore habitats in time for successful recruitment and replenishment of coastal populations[38]. Any changes in the primary productivity, the base of the ocean food web, will have profound implications for marine food webs[3]. Future predictions suggest greater seasonal variability in large-scale climatic cycles influencing the California Current region, possibly leading to increased interannual variation in the timing of spring transition[21].

A recent extreme event off the Oregon coast may provide insight on how the system could respond to changes in the spring transition. In 2005, there was a delay in the onset of coastal upwelling by two to three months[39,40]. This delay resulted in substantial changes in the physical environment during that season, including abnormally warm and fresh surface waters, trapping nutrient rich waters below[40]. Primary production was substantially lower prior to the delayed transition[41]. Pelagic fish and cephalopods were displaced poleward and towards shore and suffered reduced recruitment during early life stages[42]. Finally, marine mammals exhibited anomalous feeding patterns[43]. This example illustrates the importance of the annual cycle to Oregon's nearshore.

Interannual Cycles: ENSO is known to be sensitive to changes in background ocean surface temperatures and current temperature changes in the Pacific provide a mechanism to link changes in the frequency or magnitude of ENSO to climate change[44-46]. Over the last century, the observed behavior of ENSO has changed[47] and reconstructions to the early 1500's confirm that ENSO's 20th century behavior was unusual[48]. El Niño events have become more frequent in the last several decades[49-52]. The 1976-1977 climate shift, observed in the PDO index[14], is associated with dramatic changes in El Niño formation, including higher ocean surface temperatures and a tendency for more prolonged and stronger El Niño events[47]. Reconstructions of ENSO events back to 1525 indicate nearly half of all extreme ENSO events (including both El Niño and La Niña conditions) have occurred in the 20th century, with 30 percent in the latter half[48]. Nearly one third of all protracted ENSO events have occurred in the last century[48], though this has been suggested to be an artifact of increased frequency of events[53]. Based on observations of past events, changes in both the frequency and magnitude of ENSO events will impact Oregon nearshore waters[13,30].

Predicting how ENSO may change in a warmer climate is difficult. ENSO events are inadequately represented in global climate models used for projections[15,46]. Projections for future changes in the frequency and magnitude of ENSO events are inconsistent[21,46], possibly due to different responses to increased carbon dioxide concentrations among models[46]. Projections have also been complicated by the discovery of a novel and distinct variation of El Niño conditions that differs in the location of the maximum temperature anomalies and connections to the mid-latitude waters[45,54]. A recent study suggests that the frequency of the two variations of El Niño may change with climate change[54], however, further investigation of the connection between ENSO events and climate change is required[44,47,48].

If El Niño events continue to be stronger and more frequent, Oregon's nearshore habitats and species will be increasingly affected by those events. Extreme El Niño conditions in 1983 resulted in low overall primary productivity in Oregon and lead to longer and less productive food chains[55]. The 1997 strong El Niño dramatically affected zooplankton species compositions off the coast of Oregon, and replaced northern species with sub-tropical species of lower energy content[56]. This event also allowed multiple warm-water migratory fish species into Oregon waters, including the novel discovery of the Humboldt squid, though fewer warm water species were reported during this event than during the 1983 El Niño[57]. These two El Niño events (1983 and 1997) during a warm phase of the PDO produced the largest oceanographic anomalies off the Oregon coast in the latter half of the 20th century[13,30] and dramatic biological responses as a result[55-57].

Interdecadal Cycles: As one of the key components of North Pacific decadal variability, the PDO has dramatic impacts on the physical marine environment influencing Oregon's nearshore. There are climatic similarities in how the PDO and climate change impact the marine environment[47]. The lack of a long term observational record hinders scientists' ability to predict how a decadal source of variability, such as the PDO, may be impacted by future climate change. Only three shifts of the PDO occurred during the 20th century[14]. Currently, the PDO is not predicted to significantly change spatially or temporally during the 21st century[58]. However, models do not adequately capture the temperature dynamics associated with PDO and these results are still uncertain[58]. Warming trends over the North Pacific project an increase in winter ocean surface temperature as large as the amplitude of a PDO phase shift by mid-21st century, after which the temperature trend will dominate as the leading mode of variability in the North Pacific[15,21].

Species that are adapted to historic or recent PDO patterns may experience novel conditions with the combined effects of climate change and natural variation as soon as the first half of the 21st century[15]. Amplified by the global warming trend in temperatures, the California Current region will likely experience a greater frequency of years with lower primary productivity, such as those experienced during a positive PDO cycle[21]. Ongoing observations have shown that a positive PDO results in the dominance of warm-water zooplankton, which generally have lower energy content; this may have implications for the upper food chain[21], similar to conditions in strong El Niño years such as those shown in 1983[55]. Additional clarification is required to reduce these uncertainties and improve the accuracy of predictions in the context of future climate change[15,46,58].

Hypoxic/Anoxic Condition Changes

Seawater contains dissolved oxygen that is required for marine organisms to live. Oxygen is used when organisms respire and is replaced by contact with the sea surface, where oxygen can be exchanged with air (Figure 4). Since the middle of the 20th century, the concentration of dissolved oxygen has significantly decreased off Oregon's coast[6]. Severe inner shelf (< 230 feet or 70 meters) hypoxia (low oxygen) has been documented within the last decade[59,60] and the occurrence of hypoxia has expanded to regularly encompass approximately 80 percent of Oregon's nearshore water column between June and October during this time period[59]. In addition, 2006 marked the first documentation of anoxia (zero oxygen) in Oregon's nearshore[59]. Anoxic events are sporadic but potentially lethal for marine organisms[25,59].

Hypoxic conditions occur naturally in deeper water where organism respiration removes oxygen from seawater that cannot be easily replaced by contact with air[60]. Changes in coastal upwelling could boost the delivery of deep, low oxygen waters into nearshore waters[23,61], where respiration can further deplete the available oxygen and subject nearshore coastal ecosystems to hypoxic or anoxic events[59,60]. Upwelling intensity is projected to increase with climate change[6,23,37], which may have negative repercussions on the availability of oxygen in the nearshore.

Increased water column stratification as a result of warmer temperatures could reduce oxygen exchange with deeper waters and contribute to hypoxic conditions[62]. Consistent with predicted impacts of climate change, declines in dissolved oxygen have been documented offshore in the California Current region[62]. Wind-induced mixing can potentially improve hypoxic conditions in the shallow nearshore through the addition of oxygen at the surface[60]. However, strong upwelling favorable winds in the Oregon nearshore appeared to be insufficient to reduce stratification and the cold, oxygen-depleted waters transported shoreward decreased net oxygen concentrations further during a severe hypoxic event in 2002[60]. Severe storm events and wave heights increasing with climate change on the Oregon coast[32,63] may moderate hypoxic conditions by inducing strong mixing and oxygen exchange between the sea surface and the air. Changes in circulation can affect oxygen concentrations in the nearshore, such as the anomalous influx of water from the sub-Arctic off Oregon in 2002[64]. This change in source water substantially increased available nutrients and resulted in higher than normal respiration and hypoxic conditions in the nearshore[64]. ENSO events have also been shown to affect water temperatures and nutrients in upwelling areas[65]. Changes in the intensity and frequency of ENSO events as a result of climate change[49-52] may also impact oxygen concentrations in the nearshore.

When oxygen levels decrease, marine organisms may suffer stunted growth, slowed metabolic rates, or death[66] (Figure 4). Responses of individual organisms to hypoxic and anoxic conditions depend on the duration and intensity of the oxygen depletion[61]. Responses vary by species and depend in part on how well organisms recognize and avoid undesirable conditions[61]. Crustaceans[61,67] and echinoderms have been shown to be more sensitive to lower oxygen thresholds than annelids, molluscs, and cnidarians[61]. Hypoxic areas generally have higher mortality of sessile organisms and greater displacement of mobile species[25,60,61,66]. Both the physical conditions and the catch of multiple marine fish species and Dungeness crab deteriorate as oxygen levels decrease[68]. Some fish exhibit sub-lethal effects of hypoxia that include increased energy spent supporting respiration[67], potentially reducing feeding or other essential activities.

Some hypoxic or anoxic events can have community level impacts. In severe conditions, most sessile invertebrates will die and be replaced by bacterial mats, and reefs known to support diverse fisheries will be completely devoid of fish[59,60]. Low oxygen areas are characterized by low species richness[61,68]. Community dynamics change as trophic structure and energy pathways shift in response to hypoxia[61]. Predation rates are reduced within hypoxic areas[69] and displacement of mobile species will put additional pressure on adjacent oxygenated habitats, where increased predation could alter a broad range of marine populations[61,66]. The extent of the marine ecosystems affected by current and future hypoxic events may also be underestimated, as the conventional definition of hypoxia (< 2 parts per million or 2 milligrams O_2/liter) is lower than sublethal and lethal thresholds for many benthic marine species[67].

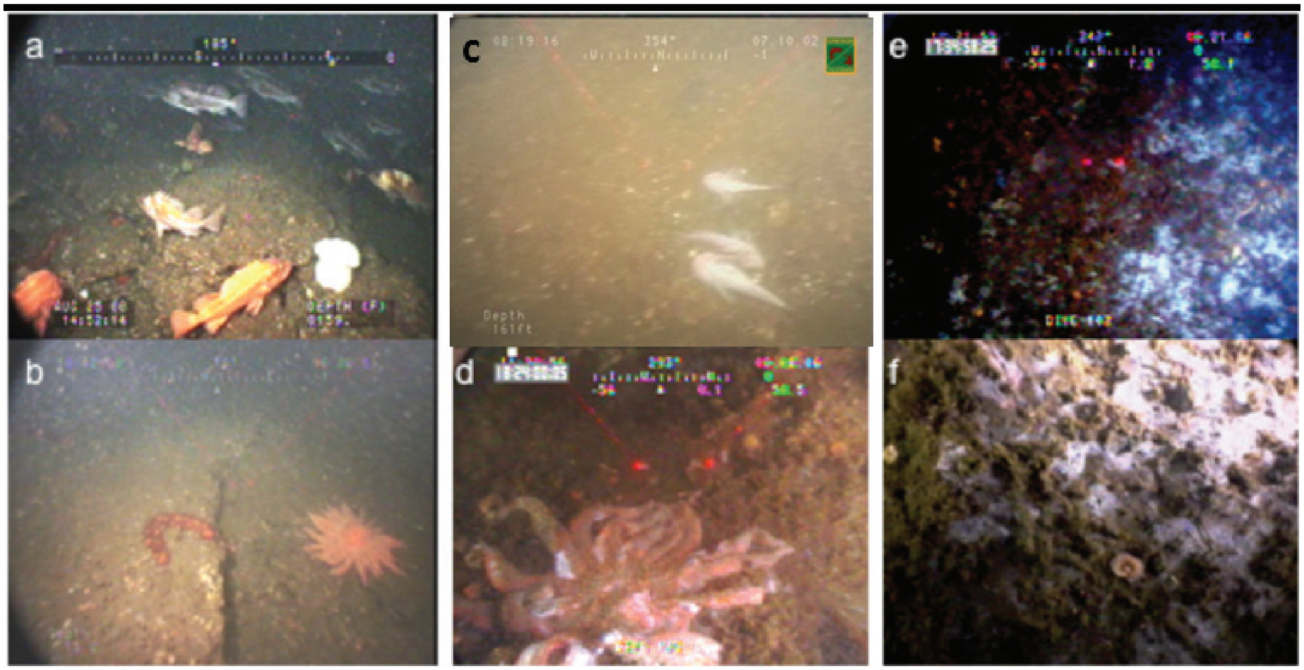
Extreme Wave Height and Storm Pattern Changes

Wave heights measured along the west coast are highest along the Oregon coastline[32]. Oregon wave heights have increased during the past 50 years[32,63]. Wave heights peak during El Niño events, but also result from background changes in warming water temperatures related to climate change[32,63]. Both the relatively low summer waves and the higher wave heights generated by winter storm events have been increasing off the Oregon coast since the mid-1970s[70]. The most extreme waves generated during winter storm events are also increasing at a higher rate than the winter average wave height[70].

As seawater warms, this thermal energy can result in storms with greater intensity, longer duration, earlier annual onset, and larger total area affected[71]. Storm intensity has also been increasing offshore of Oregon during the past 50 years and has been linked to warming water temperatures related to climate

Figure 4: Impacts of Hypoxic/Anoxic conditions in Oregon's Nearshore

Screen captures of ROV-based video transect surveys of nearshore rocky reefs off Cape Perpetua on the central Oregon coast. A) pre-anoxia rockfishes (Sebastes spp.); B) benthic invertebrates; C and D) mortality of fish and invertebrates during the 2006 anoxia event; E and F) formation of bacterial mats following 2006 anoxia event.



change[32,63]. In the North Pacific, winter storm intensity has increased but with a corresponding decrease in frequency, possibly resulting from a poleward shift in the storm track during the late 20th century[29]. The capacity for storm tracks to carry heat, precipitation, and surface wind stress toward the poles is intensified by climate change[72]. Changes in storm patterns resulting from climate change could also affect stratification persistence, wind- and wave-induced mixing, and oxygen availability in Oregon's nearshore. Though loosely associated with ENSO and PDO climatic variability, the storm intensities and track characteristics appear to be related to increasing upper atmospheric winds over the North Pole, which are strongly influenced by changes in sea surface temperature in the North Pacific[63].

Changes in storm patterns and larger wave heights correspond to greater erosion of shoreline habitats caused by increased breaker heights, wave action, and swash run-up levels[32]. The combination of sea level rise, increased storm intensity, larger wave heights and anthropogenic shoreline development reduces available sandy intertidal habitat [29,73]. This "coastal squeeze" also leads to decreases in biodiversity of invertebrates, recruitment, and prey availability for shoreline predators[73,74]. An increase in storminess may affect attachment strength of rocky inter-tidal organisms, though these have been shown in certain mussel species to vary seasonally[75]. Changes in wave action have also been shown to affect the size of intertidal algae and plants along the Oregon coast with those exposed to increased wave action being smaller with negative impacts on their reproductive capacity[76].

Changes in Sediment Movement

Sediment delivery and replenishment play key roles in shaping Oregon's nearshore sandy and soft bottom habitats. Sediment is stored, transported, and exchanged between the shoreline and ocean floor through upwelling[77], wave action, and the tides[78]. As storm intensity, wave heights, and sea levels increase due to climate change, sandy beaches are reduced between rising sea levels and adjacent upland areas[33,77,79]. Increased breaker heights and wave run-up levels can increase sediment suspension and change deposition rates[32]. Shoreline armoring and coastal development further restrict beach migration by limiting the available space for normal sediment dynamics to compensate for climate change impacts[33,34,79].

Sand tends to move rapidly away from shore during large storm events and gradually return during calm periods, thus protecting beaches from permanent erosion[33]. However, as storm patterns change as a

Shoreline impacts of climate change: Climate change impacts to shoreline habitats include rising sea levels, changes in wave heights and storm patterns, and changes to sediment movement and freshwater inputs. Low gradient sandy beaches, such as Beverly Beach on the central Oregon coast, may be at the greatest risk. ODFW Photo.

result of climate change, this delicate balance may be disrupted[33]. Shoreline armoring drastically increases sand loss during large storm events[33,34], thus adding to the impacts of greater storm intensity on the Oregon coast. With summer wave heights increasing as well[70], Oregon beaches have been unable to rebuild during that season[29].

Changes in sediment transport may also result from changes in wave direction, or from anomalous wave angles associated with major El Niño or storm events[80]. El Niño events create natural pulses in sea level and alter wave directionality along the Oregon coast, both of which can affect sediment dynamics[29,80]. During El Niño years, winter storm tracks are further to the south, which changes the general direction of waves reaching the shore[9]. This produces a redistribution of sand on beaches, creating hot spots of beach erosion that have already been observed along the Oregon coast, indicating a current sediment deficit[29]. These impacts may be intensified if El Niños become more frequent off the coast of Oregon[49-52]. As North Pacific storm tracks shift as a result of climate change[72], this may impact the sediment budgets along the Oregon coast as well.

Physical properties of sandy beaches, such as slope, particle size, and tidal variation, have significant impacts on community structure and species distribution, including polychaete worms, clams, and amphipods[81]. These and other physical beach characteristics are correlated with species richness, abundance, and biomass[78]. Low gradient sandy beaches typically house the greatest biodiversity[33]. These types of beaches are at higher risk from climate change impacts due to their erosive nature and the greater wave run-up on their gentle gradients, which could lead to the total disappearance of the habitat in extreme cases[33]. The compounded impacts of climate change have the potential to dramatically alter beach communities in Oregon's nearshore habitats.

Changes in Freshwater Inputs

Surface salinity and nutrient levels in Oregon's nearshore marine waters are strongly affected by freshwater discharge cycles. Freshwater arrives in the nearshore from rain-dominant smaller coastal rivers and streams[82], which have more localized impact[83], and from the snow-fed Columbia River[22]. Coastal watersheds along Oregon's coast are predicted to experience extreme flood events more often as a result of climate change[84]. Flooding of freshwater systems can increase erosion of riparian and estuarine sediments and have direct impacts on the substrate structure and availability of light in nearshore habitats[12]. Climate models predict increased annual precipitation in the Pacific Northwest[6,21], which will raise discharge levels of freshwater from coastal rain-fed watersheds

Changes in freshwater inputs to Oregon's nearshore: The Columbia River influences the water properties of Oregon's nearshore. Changes in freshwater inputs resulting from climate change may affect the structure and stability of the Columbia River plume, seen here in the lighter blue. Dr. Richard Brodeur, NOAA Photo.

Smaller watersheds, such as the Nestucca River, strongly affect local water properties in Oregon's nearshore. These coastal rivers and streams may experience extreme flooding events more often as precipitation patterns change as a result of climate change. ODFW and Oregon Department of Land Conservation and Development Photo.

into the nearshore during the winter and spring. Freshwater delivers nutrients to the nearshore, such as carbon and nitrogen inputs on sandy beaches[85] and nitrogen and silicate inputs to nearshore waters[83]. Oregon's nearshore may be affected by changes in the quality, quantity, and the variability in freshwater inputs resulting from climate change[83,85].

The Columbia River plume stretches hundreds of miles, moving seasonally[86]. It spreads primarily south and offshore from the mouth in the summer, and to the north and adjacent to the shore in winter, depending on climate conditions in the nearshore and freshwater inputs[86]. The average annual discharge on the Columbia River shows no significant long-term trend during the 20th century, however, the average summer discharge has decreased by approximately 30 percent during the same period[6]. This trend results from a combination of dam construction, water management regimes, and climate change[6]. The fraction of precipitation coming from snow has been decreasing in the western United States, resulting in snowpack water storage reductions that affect snow-fed rivers[87], such as the Columbia. In addition, the timing of spring stream flows in snow-fed watersheds will occur earlier in the year, shifting by 30 to 40 days by the end of the 21st century[87].

Altered freshwater inputs will modify the stratification and mixing of coastal waters and will affect riverine plume formation and stabilization[6]. With a decrease in the summer discharge, the seasonally productive Columbia River plume will be less intense and its inshore boundary next to the coastal upwelling front more diffuse[6]. The fronts that form the boundary of the Columbia River plume concentrate organisms from particular planktonic communities that provide a unique and valuable resource for upper trophic level consumers, such as salmonids and other planktivorous fishes[88]. Altered freshwater discharge levels may affect the timing of anadromous and catadromous populations to and from the nearshore[21]. For example, timing of spawning and outmigration of green sturgeon (*Acipenser medirostris*) in Oregon appears to be strongly related to both water temperatures and flow[89,90]. Changes in freshwater inputs may also affect recruitment success of juvenile fishes[91] and possibly change feeding ecology of organisms resident in Oregon's nearshore[92].

Ocean Acidification

The ocean acts as a sink, absorbing significant amounts of atmospheric carbon dioxide[3,93,94], and becomes increasingly acidic as a result[25,95]. While this absorption has slowed the growth of carbon dioxide levels in the atmosphere[4,96], the ability of the ocean to continue absorbing carbon dioxide will decrease over time[93]. Oceanic uptake of carbon dioxide will induce

OCEAN ACIDIFICATION

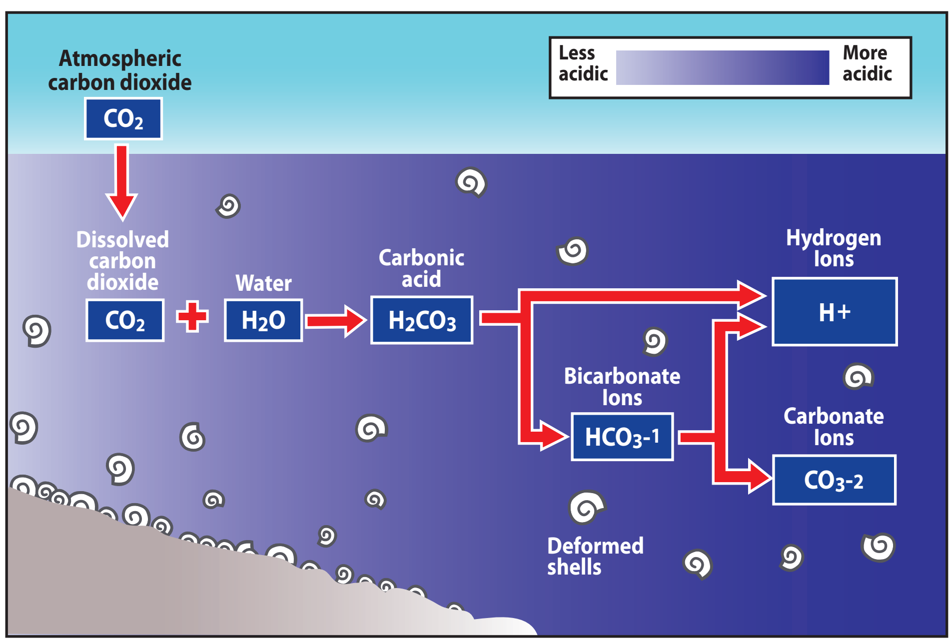


Figure 7: Ocean acidification

The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms. As more carbon dioxide is absorbed from the atmosphere, oceans will become more acidic.

fundamental changes in water chemistry that could have extreme impacts on biological ecosystems[96].

Seawater contains carbonate ions that are necessary for skeleton and shell formation of shellfish, corals, and planktonic food sources that support fisheries and upper trophic levels[71,95] (Figure 7). Ocean acidity affects the solubility and availability of the carbonate ions needed to form calcite and aragonite shells and skeletons[2], jeopardizing successful development and existence of many marine organisms[2,95]. These organisms are potentially vulnerable wherever the seawater saturation of aragonite or calcite is less than 100 percent[6]. Most of the global surface ocean is presently supersaturated for both calcite and aragonite, while deep ocean waters are typically undersaturated[2]. The boundary between these two states is called the saturation horizon, though the horizon depth varies by latitude and location[2]. The horizon depth is especially shallow (< 985 feet or 300 meters) in the northeast Pacific[95]. In the North Pacific, the calcite saturation horizon has moved ~ 130 – 330 feet (40 - 100 meters) towards the surface since pre-industrial times[2]. Recent surveys of the continental shelf off the Pacific Northwest show the saturation horizon at less than 330 feet (100 meters) below the surface, and during strong upwelling events, it can be at the ocean surface in the nearshore[95,97]. Seasonal variation in capacity of seawater to absorb carbon dioxide has been observed off the Oregon coast[98], which could lead to adverse conditions during the summer sooner in combination with upwelling events [95]. Spatial or temporal changes in the saturation state of these minerals are important for understanding how ocean acidification might impact biological systems[96].

The capacity for the ocean to continue absorbing carbon dioxide will decrease during the 21st century[2] and is projected to be more than 60 percent lower by 2100[94]. Acidity of ocean waters will continue to increase worldwide, though with some regional variation in the rate of change in the saturation horizon depth[94]. All saturation horizons are predicted to become more shallow with time[2,94] and at high latitudes, the aragonite saturation horizon may become extremely shallow within a few decades[94]. Predicted intensification of upwelling, which brings deep, naturally-acidic waters to the surface in Oregon's nearshore, may exacerbate the impacts of future ocean acidification[95]. Changes in primary productivity, water temperatures, and circulation can also affect carbonate ion availability[94]. Predicting the exact magnitude of acidification is problematic, primarily due to uncertainties with future atmospheric carbon dioxide concentrations[94].

Marine organisms may show differing responses to ocean acidification, particularly at local scales in nearshore waters, where the water characteristics are most variable and could buffer the effects of ocean acidification[99]. While some calcifying organisms require saturated conditions in order to form shells, others may be able to generate or maintain calcified structures in undersaturated conditions but at a bioenergeic cost[96]. California mussels (*Mytilus californius*) and gooseneck barnacles (*Pollicipes polymerus*) suffer reduced individual size and population abundance as waters become more acidic[25]. After only two days exposure to predicted levels of undersaturated seawater, live pteropods (pelagic gastropods) showed marked dissolution of their aragonite shells[94]. Ocean acidification may be associated with behavioral changes, such as difficulty with shell selection and slowed decision making in hermit crabs (*Pagurus bernhardus*)[100]. Exposure to acidic conditions during early life stages has been shown to disrupt recognition of predators in tropical marine fish species[101], though this has yet to be investigated for temperate fish species. The associated effects of water temperature interact with acidity to elicit complex responses with both abundance and diversity[102]. Molluscs showed the greatest reduction in abundance and diversity in response to higher acidity and warmer water temperatures, whereas nematodes increased in response to the same conditions, probably due to a reduction in predation and competition[102]. These complex responses to acidification may alter competition and predation dynamics, change species composition[25], reduce biodiversity, change community structure[102], or delay reproductive cycles[99].

Implications for Resource Management in Oregon's Nearshore

The chemical, physical, and biological changes occurring in the marine environment present major challenges for resource managers and policy makers[3]. As outlined above, many species and habitats will be affected by these changes, both positively and negatively, which may necessitate changes to current management actions[11]. New biological communities that form as species move and adapt may require a suite of new management techniques[11]. There are still many uncertainties regarding how climate change may affect Oregon's nearshore marine environment into the future[6].

Data gaps and Research Recommendations

Oregon's nearshore is a highly variable marine ecosystem that can benefit from research focused on the impacts of atmospheric carbon dioxide concentrations. Continuing to improve understanding of underlying mechanisms in variability is critical to refining predictions of the impacts on this ecosystem[71]. Research is needed to improve understanding of complex species responses and changes to habitats resulting from chemical and physical forcing[71]. Observational and monitoring networks need to be expanded in Oregon's nearshore ocean in order to continue to evaluate climate change impacts[6]. Continued investment in developing sampling capabilities should be a high priority, as well as maintaining facilities that support long term data collection[6].

A series of general research needs particularly relevant to Oregon's nearshore natural resources are listed below. These research recommendations are consistent among multiple adaptation guides available as resources for ODFW[11,103], and with the most recent assessment of climate changes related to carbon dioxide concentrations in Oregon[7]. These include:

- Climate change vulnerability assessments;
- Monitoring and evaluation of management actions;
- Long-term research on climate trends and ecosystem responses; and
- Regional downscaling of climate models.

General Recommendations for Future Management in a Changing Nearshore Climate

To address the changes occurring in Oregon's nearshore environment, resource management must remain flexible and adapt to sudden and unpredictable changes that are likely to characterize future marine ecosystems[3,104]. Adaptive management enables decision-makers to move forward with necessary actions without postponing decisions due to incomplete information[11]. Adaptation strategies will differ by the location and public preference for various alternatives. Therefore, it is important to develop site-based and goal oriented strategies for actions related to climate changes[11]. Assessments that incorporate risk exposure and vulnerability are needed to enable managers to prioritize species and habitats in need of the highest attention[3,97]. Management policies that restore and maintain critical ecological processes will play an increasingly important role[3,97] in maintaining resilience in marine environments.

Informing the Oregon Nearshore Strategy

Public participation is of the utmost importance when planning for climate change. The public process is a required element of federally-approved state wildlife action plans[11] and the controversy associated with climate change assessments could be high[11]. This supplemental document provides information for both the interested general public and for resource managers to better plan for the impacts of a changing marine climate.

Continuing to implement the Oregon Nearshore Strategy and its 16 recommendations is also considered a priority action, requiring additional resources[105]. These 16 recommendations identify some key management concerns regarding marine species and habitats[10]. While continuing to implement the recommendations from the Oregon Nearshore Strategy remains important, new actions or additional management measures may be necessary to address the unprecedented impacts of global climate change[11] and its impacts in Oregon's nearshore marine environment.

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ACKNOWLEDGEMENTS

Published in 2006, Oregon's statewide comprehensive conservation strategy is comprised of two documents: the Oregon Conservation Strategy and the Oregon Nearshore Strategy. In 2012 ODFW undertook efforts to further unify the two documents. Documenting the potential effects of climate change on species and habitats was among the tasks undertaken to better integrate the Oregon Conservation Strategy and the Oregon Nearshore Strategy. This work could not have been accomplished without the interactive efforts of the many individuals, agencies, and organizations that developed the Oregon Nearshore Strategy http://www.dfw.state.or.us/mrp/nearshore/index.asp

We would like to thank the following people and organizations that participated in the creation of supplements to the Oregon Conservation and Oregon Nearshore Strategy in 2012:

Project Funding

Funding for this project was through the Oregon Department of Fish and Wildlife State Wildlife Grant Program grant T-31-P-1 in cooperation with the U.S. Fish and Wildlife Service and Sport Fish Restoration Program.

Agencies and Institutions

James T. Carlton, Williams College; John Chapman, Oregon State University; Gayle Hansen, Oregon State University; Henry Lee, U.S. Environmental Protection Agency – Western Ecology Division; Sara O'Brien, Defenders of Wildlife, and Debbie Reusser, U.S. Geological Survey – Western Fisheries Research Center

ODFW Staff

Justin Ainsworth, Michael Arthur, Daniel Avery, Arthur Black, Rick Boatner, Ed Bowles, Caren Braby, Robin Brown, Robert Buckman, Karen Buell, Troy Buell, Kelly Corbett, Anthony D'Andrea, Alison Dauble, Lauren Dimmock, Michael Donnellan, Daniel Erickson, Brandon Ford, David Fox, Mark Freeman, Stacy Galleher, Craig Good, Scott Groth, Robert Hannah, Matthew Hunter, Kim Jones, Mari Karnowski, Delia Kelly, Meg Kenagy, Gway Kirchner, Jason Kirchner, Gregory Krutzikowsky, Alix Leferriere, Art Martin, Lynn Mattes, Bruce McIntosh, Arlene Merems, Holly Michael, Patrick Myrick, Peter Moore, Melissa Murphy, Leslie Parr, Michael Pope, Polly Rankin, Eric Rickerson, Susan Riemer, Brett Rodomsky, Steven Rumrill, Eric Schindler, Cyreis Schmitt, Maggie Sommer, Carla Sowell, P. Mitch Vance, Ellen Veille-Smuts, D. Wolfe Wagman, Stephen Williams, Bryan Wright

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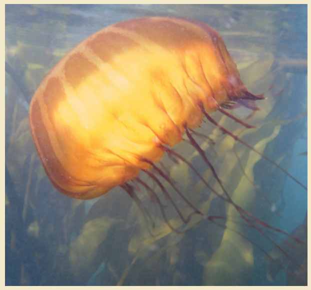


the OREGON CONSERVATION STRATEGY

FACT SHEET

Climate Change and Oregon's Nearshore Open Water Habitat

Oregon Department of Fish and Wildlife

Oregon's nearshore open water, or pelagic habitats, include the waters that overlay subtidal areas between the extreme low tide and the 30 fathom (180 feet or 55 meter) depth contour[1]. These waters are part of what is called the neritic zone, which extends out to a depth of approximately 650 feet (200 m). Open water habitats are affected by light, water temperature, stratification of water, physical mixing, and surface and underwater currents[1]. Seawater properties in nearshore habitats are affected by freshwater inputs, local environmental forcing, and large-scale conditions across the Pacific Ocean, including the offshore California Current System.

Open water habitats support many species of fish, mammals, seabirds, invertebrates, and algae; all of which are interconnected through physical, chemical, biological, geological, and human use factors. Open water habitats are very important to the ecology of the nearshore ocean. This is where plankton, free-floating organisms that provide food for many marine organisms, live[1]. Phytoplankton, microscopic plant-like organisms, are the primary producers that transform sunlight, carbon dioxide, and nutrients into oxygen and the food that form the base of the marine food web. Zooplankton, the next link in the marine food web, are planktonic animals that range in size from microscopic to several meters in diameter[1]. Zooplankton include species that live their entire lives drifting with the currents, but also many fish and invertebrates that start their lives as larvae before growing to adults. Nekton, or strong swimmers, typical in open water habitats include schooling and highly migratory species such as squid, fish, sharks, and marine mammals[1]. Open water habitats and their associated biological communities provide many benefits, including:

- primary production of biomass supporting the marine food web;
- daily, seasonal, annual, and decadal cycling of nutrients and gases;
- abundant food sources that satisfy recreational, commercial, and cultural values; and
- economic opportunities for coastal communities through fishing, tourism, energy development and shipping.

Human uses of nearshore open water habitats primarily include fishing, recreational boating, and shipping. Changes in freshwater input patterns from hydropower regulation in larger rivers also affect open water habitats. Fishing pressure, oil spills, noise pollution, introduction of non-native species, and changes to freshwater inputs are among the factors identified to be of greatest concern to managers[1]. The rise of atmospheric carbon dioxide will bring new threats and may exacerbate existing impacts to Oregon's nearshore open water species and habitats.

Consequences of Increased Carbon Dioxide for Oregon's Open Water Areas

Rising atmospheric carbon dioxide is causing a variety of impacts on the marine environment, including altered ocean circulation, warming sea temperatures, changing weather patterns, and changes to freshwater runoff and ocean chemistry[2]. As open water habitats change, individual fish and wildlife species will respond in different ways to these environmental changes. As a result, open water species may experience diminished food supply, decreased reproductive success, changes in distribution, habitat alteration, or other effects.

Changes in Oceanic Cycles

Oregon's nearshore ocean is constantly changing, making it challenging to sort out signals of climate change impacts from other environmental cycles. The relationship between each of these cycles and rising carbon dioxide levels is not well understood. Understanding how oceanic cycles function is a

Cover Photos: Northern anchovy school. Photo by Geoff Shester, Oceana, Photo. Sea nettle. ODFW Photo. Gray whales. NOAA photo.

necessary first step to understanding how climate change may alter the nearshore environment.

Climate change may alter the patterns of seasonal upwelling and downwelling that make up the annual cycle (Figure 1). Upwelling is the wind-driven circulation of cold, nutrient-rich water from deep in the ocean up to nearshore waters in the spring and summer. Downwelling is the movement of warmer, oxygen-rich surface water from the nearshore to deeper waters during fall and winter. As the climate warms, the alongshore winds that drive this cycle may grow stronger, therefore intensifying upwelling[3]. As a consequence of climate change, predictions suggest that the spring transition from downwelling to upwelling conditions will be delayed and followed by stronger upwelling effects later in the season[4,5].

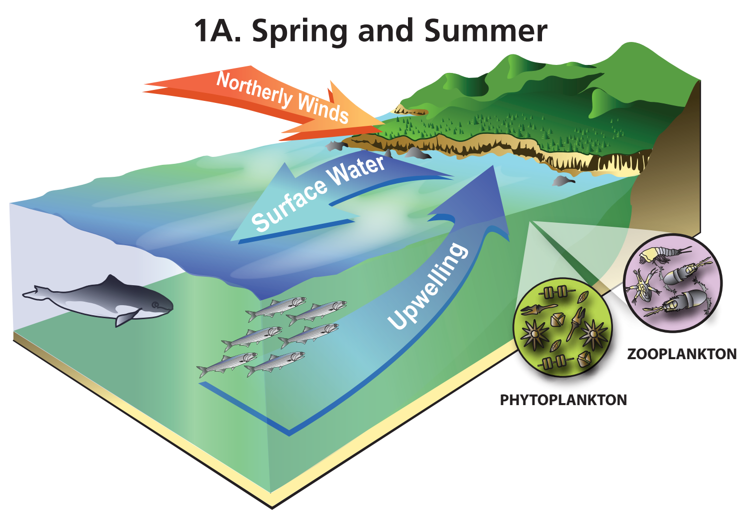
Both upwelling and downwelling are important to maintaining the base of the marine food web, and this dynamic may become out of balance as ocean conditions become less predictable. The timing and strength of winds affecting upwelling play a major role in determining annual productivity and species diversity[6,7]. During upwelling conditions, zooplankton populations are higher but species diversity tends to be lower than during winter downwelling conditions[8]. Along with upwelled water, plankton is carried from the highly productive continental shelf and broadly distributed by the California Current System[9].

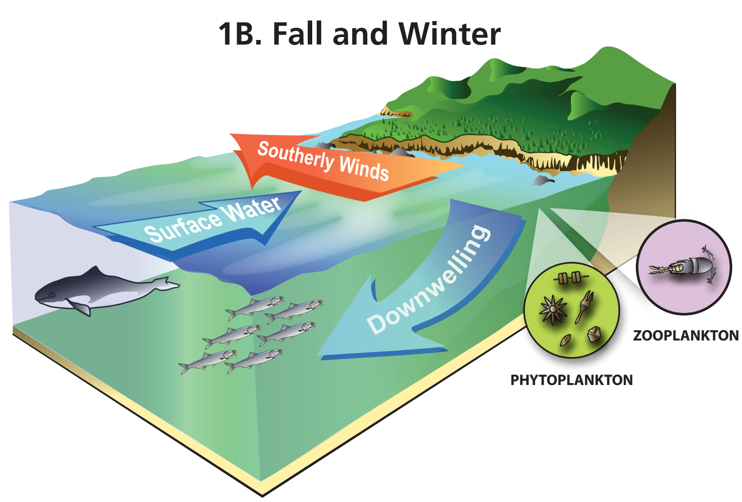
When the delivery of nutrient-rich bottom water is delayed, primary production of marine algae and phytoplankton are also postponed[5]. Transport of planktonic fish and invertebrate larvae in circulating waters may not occur in time for successful replenishment of coastal populations[5]. Many migratory species, such as whiting, sardine, and humpback whales, time movement to maximize exposure to productive waters to benefit feeding, spawning or breeding requirements[10]. Marine species will likely need to make adjustments to regular timing of life activities and may respond by moving north or towards shore[10,11]. Many nearshore marine fish, including rockfishes, salmon, and sardine, require strong upwelling for high offspring survival[10,11].

Figure 1. Upwelling and Downwelling

1A. During spring and summer, winds from the north blow parallel to the shore, exerting drag on the ocean's surface. The combination of energy transfer downward in the water column and the earth's rotation move surface waters off shore, 90 degrees to the right of the wind direction. This water is replaced by cold, nutrient rich, low oxygen waters from the deep offshore ocean. This process is called upwelling. During spring/summer upwelling production of nearshore plants and animals is at its highest.

1B. During fall and winter, winds from the south blow parallel to the shore driving surface waters shoreward where they submerge in a process called downwelling. Downwelling transports nearshore surface waters to resupply deep offshore waters with oxygen. Storm activity is highest, and runoff from precipitation over land contributes to mixing nearshore waters and loading the environment with oxygen and freshwater inputs





In addition to annual cycles, interannual (multi-year) cycles such as atypical conditions from the El Niño Southern Oscillation (ENSO) also cause physical changes in open water habitats[13]. During the ENSO cycle, water temperatures alternate between warmer El Niño and cooler La Niña conditions. The cycle typically occurs over a period of three to seven years with warm or cold conditions persisting for six to twelve months at a time[12,13]. El Niño events have intensified in recent decades and may become more intense and more frequent in coming years[14-17].

El Niño events can affect upwelling, water circulation, and temperatures[13]. In turn, this affects primary productivity, species distribution and abundance, and marine food web dynamics in Oregon's nearshore[13]. Severe El Niño events reduce planktonic food-sources, redistribute algae to greater depth, and decimate localized populations of kelp, fish, or invertebrates[13],[15]. Strong El Niño conditions from 1983 resulted in low overall plankton productivity and an influx of southern species in Oregon, which dramatically affected food web dynamics[18].

Warming Ocean Temperatures

The world's oceans are warming. For most of the past century, significant changes in sea surface temperature have been recorded in the northeast Pacific[13] as most of the heat added to the atmosphere is absorbed by the ocean[19]. Oregon's coastal surface waters have warmed an average of 0.5° F (0.3° C) per decade since the mid-20th century and are predicted to increase an average of 2.2° F (1.2° C) by the mid-21st century[14]. Warming conditions can affect open water community in many ways including decreased plankton productivity, changes in species abundance, and shifts in species distribution northward[6,10].

As ocean temperatures warm, distributions of fish and other mobile animals are moving northward, likely associated with species-specific temperature requirements[6,20]. Northward population shifts may also be linked to temperature-associated food source availability[6]. Around the globe, distributions of many tuna, shark, and marine mammal species may shift significantly as a result of warming sea temperatures[10,21]. Fish and marine mammal biodiversity may actually increase off the Oregon coast, with an influx of warm-water species from the south[5]. New interactions among species that do not currently overlap in distribution may alter nearshore community dynamics. Some fish species exhibit enhanced growth and survival when cool water zooplankton are available because this food base provides greater biomass and higher energy content[6]. The abundance, distribution, and spawning success of Pacific sardine are strongly influenced by sea surface temperature[22]. Jellyfish abundance can change dramatically from year to year based on fluctuations in sea surface temperature[23]. Jellyfish can quickly replace fish as dominant species if populations are subjected to major environmental change[24].

Sea nettle, a common jellyfish in Oregon's nearshore. ODFW Photo.

Warming ocean temperatures can have consequences for successful reproduction. Some marine species will establish reproductive populations in new regions with suitable conditions[10]. For example, hake and Pacific sardine have recently spawned in waters off Oregon and Washington[22,25]. Other species habitually return to established sites even if conditions are less conducive to the survival of young. Many shark species can adapt to variations in water temperature as necessary to follow changing prey distributions, but their young may be more vulnerable to warmer temperatures at established pupping sites[10]. Overall, open water communities are predicted to respond to warming conditions with altered community structure and shifts in species distribution and diversity.

Changes in Freshwater Input

Climate change will alter frequency, magnitude and duration of freshwater inputs into the nearshore ocean. As Oregon's climate warms, winter and spring flooding may increase while summer and fall precipitation may diminish. This would lead to higher seasonal extremes in the amount of freshwater versus saltwater in nearshore ocean waters, affecting nearshore habitats and species. The amount of freshwater input changes the salinity and density of seawater. Changes in freshwater input may alter river runoff, circulation and nutrient levels in nearshore waters.

Climate change will affect Oregon's small coastal watersheds with shifts in runoff strength, timing, and duration, altering nutrient inputs and water properties of coastal marine waters[10,14,26]. Many migratory species, such as hake, sardine, mackerels, sharks, and salmon are drawn to specific environmental conditions that occur during high or low runoff seasons[27]. Consequently, changes in timing, strength, or quality of freshwater runoff could alter the species composition of nearshore open water communities.

When the large Columbia River empties into the ocean, it creates a plume that stretches hundreds of miles[1,28], and the area where the plume meets the ocean generates productive conditions that attract many species of fish, seabirds, and marine mammals[1,27]. Planktonic communities concentrate along this boundary and provide a unique and valuable resource for upper trophic level consumers, like salmon and other fishes[29].

Throughout the 20th century, the average summer discharge from the Columbia River, also known as summer base flow, has decreased by approximately 30 percent due to the combined effects of hydroelectric regulation, water management regimes, and climate change[14]. With decreased summer base flows, formation and stability of the productive Columbia River plume will be less intense and its inshore boundary next to the coastal upwelling front will be more diffuse[10,14]. These impacts may affect the timing of fish migration to and from the nearshore, survival of juvenile fishes, and food availability for animals residing in Oregon's nearshore[10,27,30].

Changes in Hypoxia

Hypoxia is defined as conditions in which dissolved oxygen in seawater is below the level necessary for most animals to survive. An intensification of upwelling resulting from climate change may exacerbate the frequency and duration of hypoxia (low oxygen) and anoxia (no oxygen) in Oregon's open water habitats. The occurrence of hypoxia was first documented in Oregon's nearshore in 2000[31]. In addition, anoxia was initially documented in 2006[31]. Dissolved oxygen concentrations have been declining in Oregon's coastal waters since the 1960s[14].

Hypoxic conditions are particularly strong along Oregon's central shelf near Stonewall and Heceta Banks offshore of Newport and Florence[14]. Since 2000, hypoxia has been observed within approximately 80 percent of the nearshore water column between June and October[31]. Areas affected by hypoxia increase in size during summer upwelling[14]. Respiration can depress low oxygen levels in the upwelled water even further especially in highly productive areas[32].

Marine organisms require dissolved oxygen to live and when dissolved oxygen levels decrease, marine species may suffer stunted growth, abnormal behavior, or death[33,34]. The physical condition and catch of many marine fish species declines as oxygen levels decrease[35]. Many fish adapt to hypoxic conditions by changing behaviors, such as a 70% decrease in swimming activity by juvenile white sturgeon[36]. When deprived of sufficient oxygen, northern anchovy and other schooling open water fish suppress swimming patterns and behaviors that normally protect the school against predators[34]. In 2002, a particularly strong hypoxic event led to fish kills in the nearshore[1,32].

In contrast, some invertebrate species, such as moon jellyfish and Humboldt squid, are more tolerant of hypoxic conditions with consequences for species composition and trophic relationships[34]. In hypoxic conditions, the animals that eat jellyfish move elsewhere and moon jellyfish populations increase dramatically[34,37]. Fish larvae become sluggish and are less able to escape being eaten by moon jellyfish, causing community composition to become out of balance[34,37]. In the eastern Pacific Ocean, Humboldt squid have expanded their range through periodic warmer ocean temperatures. In hypoxic areas, Humboldt squid can outcompete other predators, such as whiting or tuna, by using the low-oxygen areas to feed on organisms that other predators can't reach[34]. The spread of hypoxia resulting from intensified upwelling may alter nearshore community relationships and ecosystem resilience may be reduced.

OCEAN ACIDIFICATION

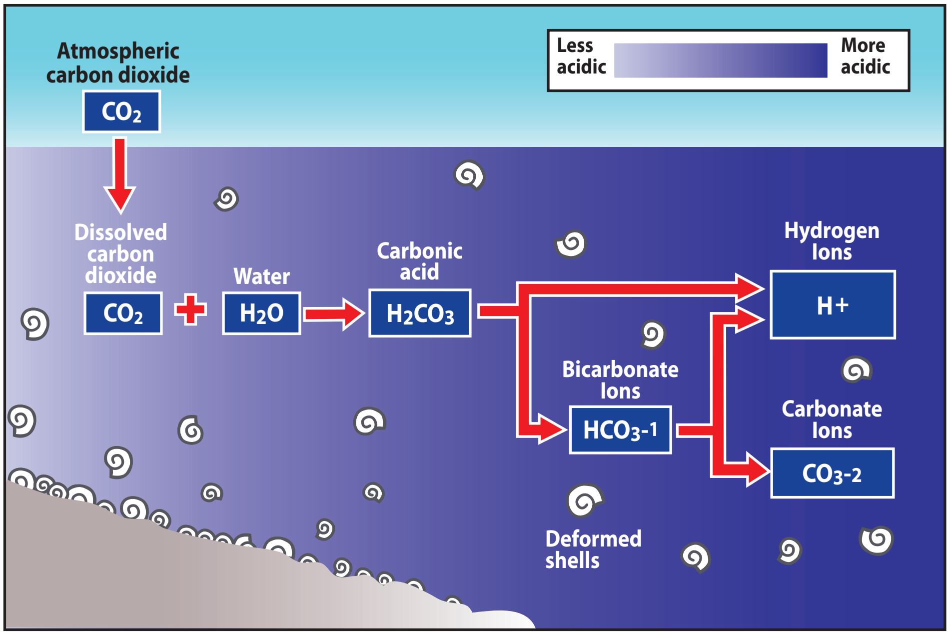


Figure 2. *Ocean acidification* **The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms. As more carbon dioxide is absorbed from the atmosphere, oceans will become more acidic.**

Ocean Acidification

The world's oceans are becoming increasingly acidic as more atmospheric carbon dioxide is absorbed into the ocean[6,14,38]. At the same time, deeper waters can become naturally acidic as living organisms consume oxygen and expel carbon dioxide. During periods of strong upwelling, these acidic waters can be transported into Oregon's nearshore[6,14,38].

Seawater contains carbonate ions that are necessary for skeleton and shell formation. When carbon dioxide reacts with seawater, the availability of carbonate is reduced (Figure 2) and successful development of shellfish and planktonic food sources that form the base of the marine food web and support fisheries, including salmon and groundfish, is threatened[14,38,39]. Each time the abundance of a single species changes, there is a possibility of cascading effects throughout the open water community. Certain plankton, pelagic snails, and other important prey are less able to maintain structural integrity in acidic waters[40-42]. These effects could lead to higher mortality of significant food sources for upper trophic levels[38,40] and larval fishes[12]. These declines alter competition and predation dynamics and may contribute to increased populations of non-calcifying organisms[6]. As ocean acidification alters community dynamics, open water communities may become less resilient to climate change impacts or any other environmental stressors.

Managing for Climate-adaptive Open Water Habitats

Open water marine species are subject to a host of stressors including fishing and changes in water quality and chemistry. Climate change impacts will likely exacerbate these pressures in the coming years, putting additional strain on marine systems[39]. Many aspects of climate change impacts on nearshore marine systems remain poorly understood. More information is needed regarding large-scale or long-term environmental variability and rates of change. Additional information pertaining to the relationships between ocean circulation, local habitats, marine populations, and human uses will help inform future management actions. Cooperative research and evaluation of threats to marine ecosystems, including climate change, could help bridge data gaps and overcome a limited understanding of all impacts to open water habitats and species[43].

Oceanographic instrument that measures water properties at various depths being deployed from a research vessel. Jay Peterson photo.

Oregon's open water areas are publicly owned, resulting in a complex mix of laws, rules, and programs governing the use, conservation, and management of Oregon's marine resources[1]. Management of marine resources should be flexible in order to adapt to climate change impacts and maintain resource sustainability in the future[12]. Currently, the Oregon Department of Fish and Wildlife is working with a number of conservation partners to support ongoing efforts and develop new methods to conserve the ecological value of open water habitats in the face of various stressors, including climate change. These include:

- determining the influence of ocean conditions on long-term recruitment and survival, and monitoring long-term trends in marine populations;
- updating information regarding ocean circulation, water properties, and relationships between local Oregon conditions and global ocean and climate conditions;
- conducting gear selectivity and bycatch reduction studies to reduce fishing impacts on open water communities;
- investigating larval dispersal potential, and inferring limitations to genetic exchange;
- enhancing nearshore research and monitoring programs to meet data needs for conservation and management;
- generating baseline data to understand existing resources and conditions; and
- determining life history characteristics for marine species to develop new stock assessments and population status indicators.

These efforts represent large scientific questions that cannot be fully addressed with individual research projects. As resource managers learn more about the effects of climate change on open water communities, that knowledge can be applied to the cumulative effects on habitats and organisms where multiple impacts are occurring simultaneously. Management approaches must then adapt to best address these effects. Adaptive management is based on an understanding of environmental processes, and an acceptance of large-scale changes that can be addressed by increasing ecological resilience[40].

Species responses to short-term changes in environmental conditions need to be documented in order to predict how local populations are likely to respond when exposed to large-scale or long-term climate change impacts[40]. Understanding of these variables will continue over time by building the region's research base and by emphasizing nearshore research. Informed by the results of ongoing research and collaborative efforts, management strategies can be designed to reduce existing sources of stress on open water habitats and the fish and wildlife that utilize them. By minimizing existing impacts, future threats to open water habitats can be moderated and nearshore communities can better cope with climate change and other current and future threats.

Primary Productivity and Climate Change

Photosynthesis by phytoplankton, microscopic plant-like organisms, is a critical link in nutrient cycling in the ocean[12,45]. As the base of the marine food web, phytoplankton will respond first to climate change impacts[12]. Globally, primary productivity from oceanic phytoplankton has decreased over the last decade[45]. Oceanic productivity is negatively affected by warmer water temperatures resulting from both oceanic cycles or as the oceans warm due to climate change[45].

Off the Oregon coast, primary productivity levels change from year to year and are affected by the annual upwelling cycle and interannual ENSO events[12]. With climate change, the onset of spring upwelling may be delayed[12], altering the nutrients available for primary productivity in the spring in Oregon's nearshore. More nutrients may be available through an intensification of upwelling, driving stronger productivity and increasing the probability of hypoxic and anoxic events off the Oregon coast[12]. El Niño events may become more intense and more frequent[14-17], bringing warmer waters to the Oregon coast and reducing available nutrients at the ocean's surface. The delivery of nutrients into the nearshore by coastal rivers and streams becomes important during the winter months[22]. As freshwater runoff changes, the timing and amount of nutrients may be affected and could alter the growth and distribution of phytoplankton in the nearshore[12]. All of these impacts are consistent with global trends in primary productivity as the climate changes and will have dramatic impacts on marine food webs.

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the OREGON CONSERVATION STRATEGY

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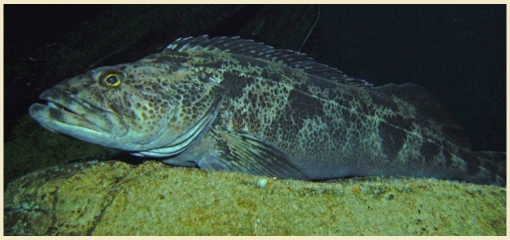

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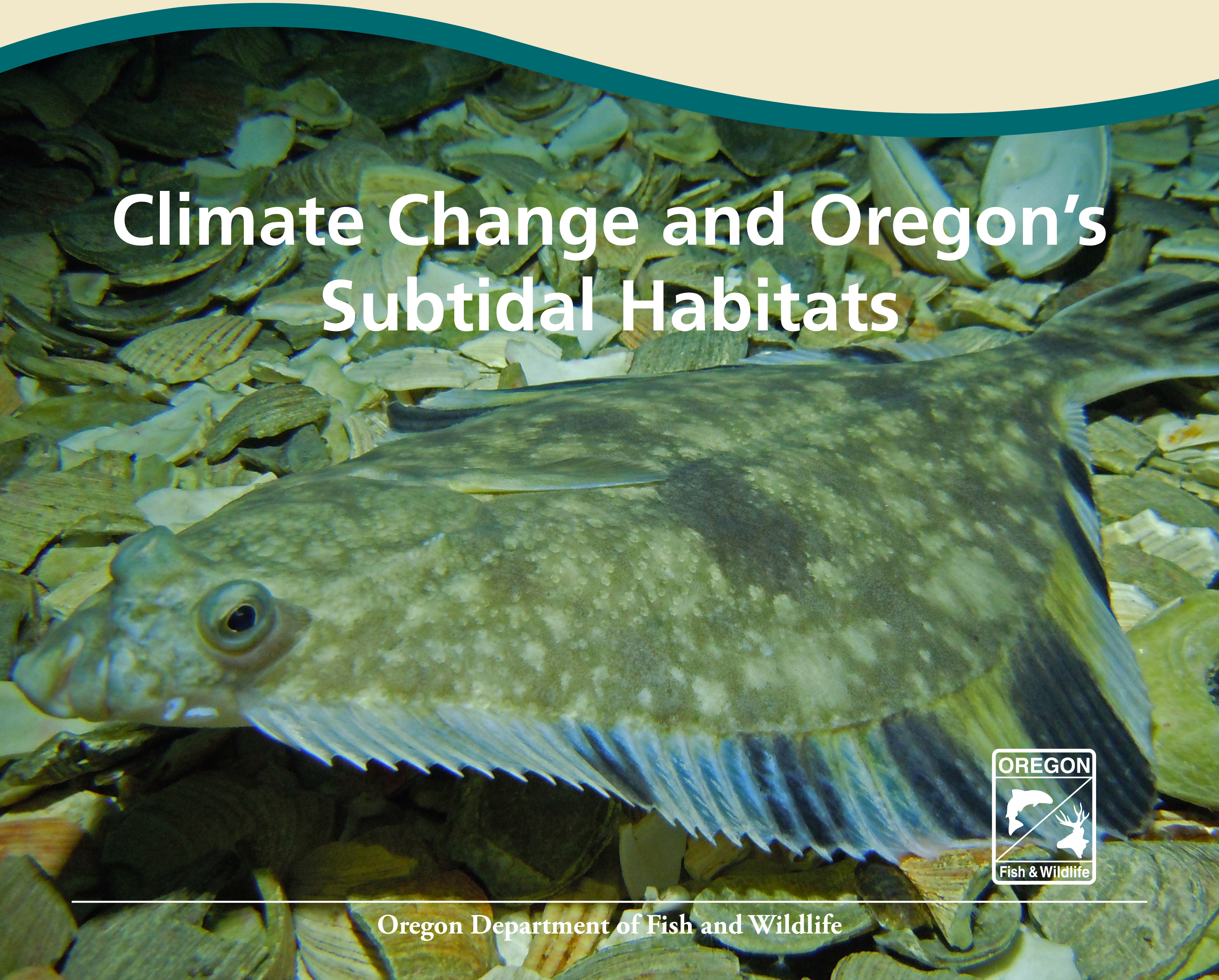


Climate Change and Oregon's Subtidal Habitats

Oregon Department of Fish and Wildlife

Oregon's subtidal habitats include soft-bottom and rocky areas that occur between the extreme low tide line and the 30 fathom (180 feet or 55 meter) depth contour[1]. This narrow strip of coastal ocean falls between the intertidal area and the deep sea. It is heavily influenced by oceanographic processes, underwater currents, and both physical and chemical water properties[1]. Ocean currents, which vary widely by location, season and tidal cycle, influence subtidal habitats in a variety of ways including erosion, sand scour, and/or burial and movement of organisms[1]. The temperature, salinity, nutrient level, and oxygen content of the waters surrounding subtidal habitats are affected by freshwater inputs, local environmental forcing, and much larger scale conditions across the Pacific Ocean[1].

The variety of topography, substrate characteristics, and depths within and among subtidal habitats produce a densely packed and highly diverse set of microhabitats[1], which support abundant communities of marine organisms including numerous invertebrates, fish, algae, and marine plants. An estimated 98 percent of the world's marine species live in or on the seafloor[2]. Subtidal habitats provide many benefits including:

- rocky substrate for attached invertebrates and habitat-forming organisms;
- nursery areas for juvenile fish;
- economic opportunities for coastal communities through fishing, tourism, and recreation;
- slowing of currents by rocky reefs, which enhances the capture of drifting food-source organisms, especially in reefs with large kelp beds;
- food sources (e.g., groundfish, sea urchins, Dungeness crab, flatfish species) for human consumption that satisfy recreational, commercial, and cultural values;
- kelp beds on shallow reefs that provide vertical structure and increase the microhabitats available on the seafloor
- nutrient cycling by deposit feeders and micro-organisms living within soft-bottom sediments; and
- an abundance of forage organisms and feeding areas that support birds, fish, and marine mammals.

Human uses of subtidal habitats include fishing, recreation, underwater cables and outflow pipes, and at-sea disposal of dredged material. Vessel traffic in nearshore waters can increase sediment contamination through oil discharges that collect in the subtidal seabed[1]. These stressors may lead to changes in water quality (e.g., pollution), community dynamics (e.g., predation, competition), and physical factors such as temperature, availability of nutrients, water turbidity, and storm events[1]. The rise of atmospheric carbon dioxide will bring new threats and may exacerbate existing impacts to Oregon's subtidal species and habitats.

Consequences of Increased Carbon Dioxide for Oregon's Subtidal Areas

Rising atmospheric carbon dioxide is causing a variety of impacts on the marine environment, including altered ocean circulation, less dissolved oxygen, increasing sea temperatures, and changes in freshwater input and ocean chemistry[3]. Although the effects of these impacts on subtidal organisms are not fully understood, seafloor habitats are expected to undergo significant changes[4]. As subtidal habitats change, individual species will respond in different ways to these environmental changes. Subtidal species may experience diminished food supplies, decreased reproductive success, changes in distribution, or habitat alteration, among others.

Subtidal communities are dominated by species with long-lived pelagic larval stages. During these life stages, larvae may float long distances within the water column and disperse to other suitable habitats spread out

Cover Photos: Red rock crab, lingcod and starry flounder. Taylor Frierson photos.

along the coastline[5]. Populations that are relatively isolated on patchy habitat are reliant on larval dispersal for replenishment, a process that may be altered by environmental change[5]. These changes could potentially lead to insufficient replenishment to maintain populations and reduced genetic variability, as well as altered community structure[5].

Changes in Oceanic Cycles

Dungeness crab megalopae (baby crab). ODFW photo.

Adult Dungeness crab. ODFW photo.

Oregon's nearshore ocean is constantly changing, making it challenging to sort out signals of climate change impacts from other environmental cycles. The relationship between each of these cycles and rising carbon dioxide levels is not well understood. Understanding how oceanic cycles function is a necessary first step to understanding how climate change may alter the nearshore environment.

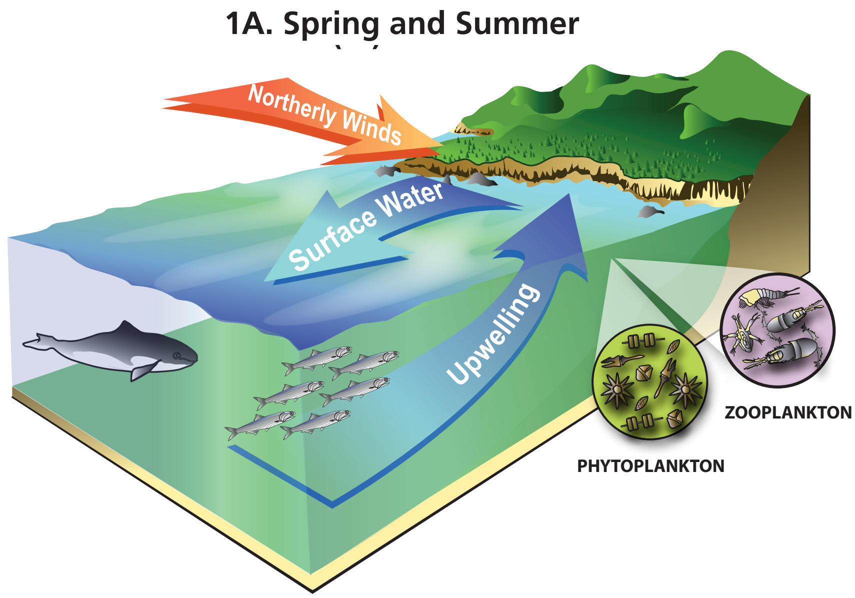
Climate change may alter the patterns of seasonal upwelling and downwelling that make up the annual cycle (Figure 1). Upwelling is the wind-driven circulation of cold, nutrient-rich water from deep in the ocean up to nearshore waters in the spring and summer. Downwelling is the movement of warmer, oxygen-rich surface water from the nearshore to deeper waters during fall and winter. As the climate warms, the alongshore winds that drive this cycle may grow stronger, therefore intensifying upwelling[6]. As a consequence of climate change, predictions suggest that the spring transition from downwelling to upwelling conditions will be delayed and followed by stronger upwelling effects later in the season[7,8].

Both upwelling and downwelling are important to maintaining the base of the marine food web, annual productivity, and species diversity. When the delivery of nutrient-rich bottom water is delayed, primary production of marine algae and phytoplankton are also postponed[8]. Transport of planktonic fish and invertebrate larvae in circulating waters to and from subtidal habitats may not occur in time for successful replenishment of coastal populations[8]. If upwelling continues for extended periods without relaxation, larvae are forced to stay in offshore waters where they will not settle and grow in appropriate subtidal habitat.

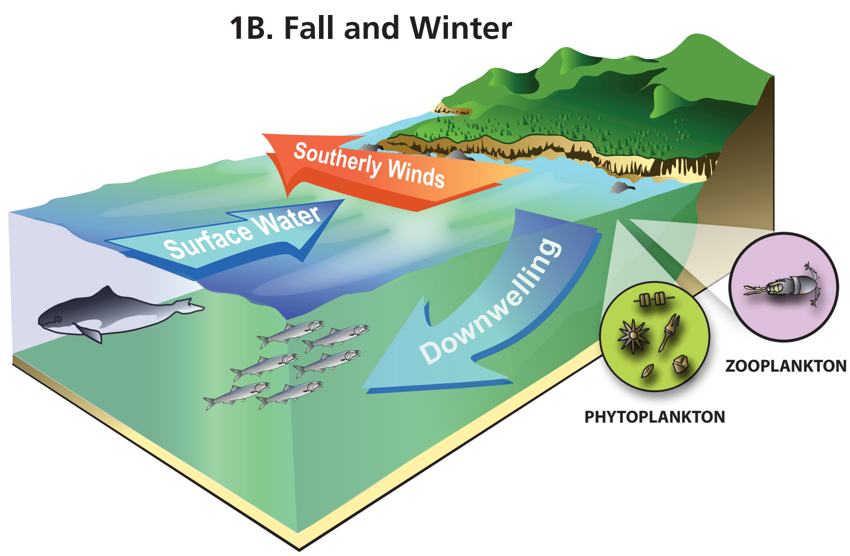
As an example, Dungeness crab larvae generally hatch mid-winter and spend three months developing in open waters far from shore before returning to the coastline in upwelled waters in early March[9]. If upwelling is delayed, megalopae (baby crabs) spend more time in open waters where they are eaten by other animals and consequently, fewer crabs will survive to migrate back to nearshore waters[9]. Catches of adult Dungeness crab demonstrate the direct relationship between timing of upwelling onset, successful development of megalopae, and subsequent abundance of adult crabs[9].

Figure 1. Upwelling and Downwelling

1A. During spring and summer, winds from the north blow parallel to the shore, exerting drag on the ocean's surface. The combination of energy transfer downward in the water column and the earth's rotation move surface waters off shore, 90 degrees to the right of the wind direction. This water is replaced by cold, nutrient rich, low oxygen waters from the deep offshore ocean. This process is called upwelling. During spring/summer, upwelling production of nearshore plants and animals is at its highest.



1B. During fall and winter, winds from the south blow parallel to the shore driving surface waters shoreward where they submerge in a process called downwelling. Downwelling transports nearshore surface waters to resupply deep offshore waters with oxygen. Storm activity is highest, and runoff from precipitation over land contributes to mixing nearshore waters and loading the environment with oxygen and freshwater inputs.



In addition to annual cycles, interannual (multi-year) cycles, such as atypical conditions from the El Niño Southern Oscillation (ENSO), also cause physical changes to subtidal habitats[10]. During the ENSO cycle, water temperatures alternate between warmer El Niño and cooler La Niña conditions. The cycle typically occurs over a period of three to seven years with warm or cold conditions persisting for six to twelve months at a time[4,10]. El Niño events have intensified in recent decades and may become more intense and more frequent in coming years[11-14].

El Niño events can affect upwelling, water circulation and temperatures[10]. In turn, this affects primary productivity, species distribution and abundance, and marine food web dynamics in Oregon's nearshore[10]. Severe El Niño events reduce planktonic food-sources, redistribute algae to greater depth, or destroy localized populations of kelp, fish, or invertebrates[10,12].

Populations of young rockfishes have low abundances during El Niño conditions[15]. Strong El Niño conditions from 1983 resulted in low overall plankton productivity and an influx of southern species to Oregon waters, which dramatically affected food web dynamics[16].

Changes in Hypoxia

Hypoxia is defined as the condition in which dissolved oxygen in seawater is below the level necessary for most animals to survive. An intensification of upwelling resulting from climate change may exacerbate the frequency and duration of hypoxia (low oxygen) and anoxia (no oxygen) in Oregon's subtidal habitats. The occurrence of hypoxia was first documented in Oregon's nearshore in 2000[17]. In addition, anoxia was initially documented in 2006[17,18]. Dissolved oxygen concentrations have been declining in Oregon's coastal waters since the 1960s[11].

Hypoxic conditions are particularly strong near Stonewall and Heceta Banks offshore of Newport and Florence, where low oxygen concentrations are found relatively close to shore[11]. Since 2000, hypoxia has been observed within approximately 80 percent of the nearshore water column between June and October[17]. Areas affected by hypoxia increase in size during summer upwelling[11]. Respiration can depress low oxygen levels in the upwelled water even further especially in highly productive areas[5].

Marine organisms require dissolved oxygen to live, and as oxygen levels decrease with increasing severity of hypoxia, individuals may suffer stunted growth, slowed metabolic rates, or death[19]. To some extent, hypoxic conditions occur naturally within soft-bottom sediments, where animals consume oxygen and release carbon dioxide, and where some animals may have increased tolerance to low oxygen levels[2]. However, many subtidal organisms are not tolerant to low concentrations of oxygen.

During a hypoxic event in 2002, crab mortality, which does not normally occur in commercial fishery pots, reached greater than 75 percent and underwater video surveys documented complete, or nearly complete mortality of affected rocky reef communities comprised of rockfish and other fish and invertebrates[20]. Seasonally-persistent anoxia or hypoxia greatly impacts organisms that live on the ocean floor or in bottom waters[18]. Hypoxic areas have greater displacement of mobile species that are driven out of preferred habitats[18-21]. In severe conditions, most invertebrates will die and be replaced by bacterial mats, and reefs known to support diverse rockfish fisheries will be completely devoid of fish[17].

Displacement of mobile species will put additional pressure on adjacent habitats, where increased predation could alter a broad range of marine populations[19,20]. In some instances, predators living on soft-bottom sediments will be forced to leave feeding grounds due to hypoxic conditions, relieving predatory control of prey populations living within sediments[22]. If prey animals are tolerant to hypoxic conditions, then populations would be expected to increase and habitat quality may be indirectly affected[22]. If upwelling intensity increases with climate change, there may be negative repercussions on the availability of oxygen for subtidal species and habitats.

Warming Ocean Temperatures

The world's oceans are warming. For most of the past century, significant changes in sea surface temperature have been recorded in the northeast Pacific[10] as most of the added heat to the atmosphere is absorbed by the ocean[23]. Oregon's coastal surface waters have warmed an average of 0.5° F (0.3° C) per decade since mid-20th century and are predicted to increase an average of 2.2° F (1.2° C) by the mid-21st century[11]. Warming conditions can affect subtidal communities in many ways including decreased primary productivity, changes in species abundance and shifts in species distribution toward the poles[18,24].

Ocean stratification is the natural formation of layers of water with different densities and temperatures. In general, stratified layers of warm surface waters mix less easily with colder, deeper water, but as the climate warms, the upper ocean will most likely be more stratified on average[24] making ocean mixing less effective at bringing nutrients to the surface, thereby reducing primary productivity[23,24]. Reduced productivity means less food is available at the base of marine food webs[25], potentially affecting subtidal species.

As ocean temperatures warm, distributions of fish and other mobile animals are moving northward, likely associated with species-specific temperature requirements[18,26]. Northward population shifts may also be linked to temperature-associated food source availability[18]. Some fish species exhibit enhanced growth and survival when cool water zooplankton is available because this food base provides greater biomass and higher energy content[18]. While some species may react poorly to changing temperature conditions, others, including arthropods and annelids, may be less vulnerable[27]. Predominant species abundance may shift from one group to another[27]. Overall, biological communities on and in seafloor habitats are predicted to respond to warming conditions with altered community structure and shifts in species diversity[27].

Ocean Acidification

The world's oceans are becoming increasingly acidic as more atmospheric carbon dioxide is absorbed into the ocean[11,18,28]. At the same time, deeper waters can become naturally acidic as living organisms consume oxygen and expel carbon dioxide. During periods of strong upwelling, these acidic waters can be transported into Oregon's nearshore[11,18,28].

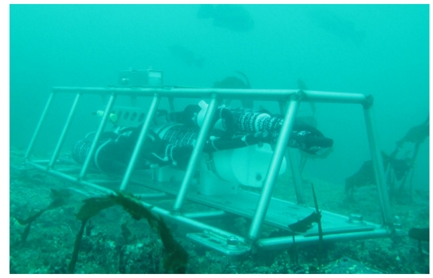
Seawater contains carbonate ions that are necessary for skeleton and shell formation. However, when carbon dioxide reacts with seawater, the availability of carbonate is reduced and successful development of shellfish, corals, and planktonic food sources that support fisheries, including salmon and groundfish, is threatened[11,28,29] (Figure 2).

Shell-forming organisms may suffer reduced individual size and decreased populations as seawater becomes more acidic[18]. Organisms living on or beneath soft bottom sediments are also vulnerable to impacts of acidification. Acidification has resulted in decreased fertilization rates in sea urchins, and may affect the ability of other organisms to grow and reproduce normally[2]. More acidic conditions can lead to changes in population abundances due to altered predation dynamics. Exposure to seawater simulating ocean acidification during early life stages of rocky reef tropical fish has been shown to disrupt recognition of predators, leading to increased predation[30], though this has yet to be investigated for fish species locally abundant in Oregon. Reduced fish abundance can relieve local predation and may contribute to increased populations of algae and non-calcifying organisms[18].

Each time the abundance of a single species changes, there is a possibility of cascading effects throughout the subtidal community. If acidification leads to the removal or reduced populations of one species, biodiversity would be reduced and community food webs would become less complex[2]. Subtidal communities would be less able to support some marine animals whose prey are reduced or removed due to sensitivity to acidic conditions, decreasing overall community resilience.

Managing for Climate-adaptive Subtidal Areas

ODFW's remotely operated vehicle being deployed. ODFW photo.



Underwater oceanographic data collection. ODFW photo.

Subtidal marine species are subject to a host of stressors including habitat alteration and fishing. Climate change impacts will exacerbate these pressures in the coming years, putting additional strain on marine systems[29]. Many aspects of climate change impacts on nearshore marine systems remain poorly understood. More information is needed regarding large-scale or long-term environmental variability and rates of change.

Additional information pertaining to the relationships between ocean circulation, local habitats, marine populations, and human uses will help inform future management actions. Cooperative research and evaluation of threats to marine ecosystems, including climate change, could help bridge data gaps and overcome a limited understanding of all impacts to subtidal habitats and species[31].

Oregon's subtidal areas are publicly owned, resulting in a complex mix of laws, rules and programs governing the use, conservation, and management of Oregon's marine resources[1]. Management of marine resources should be

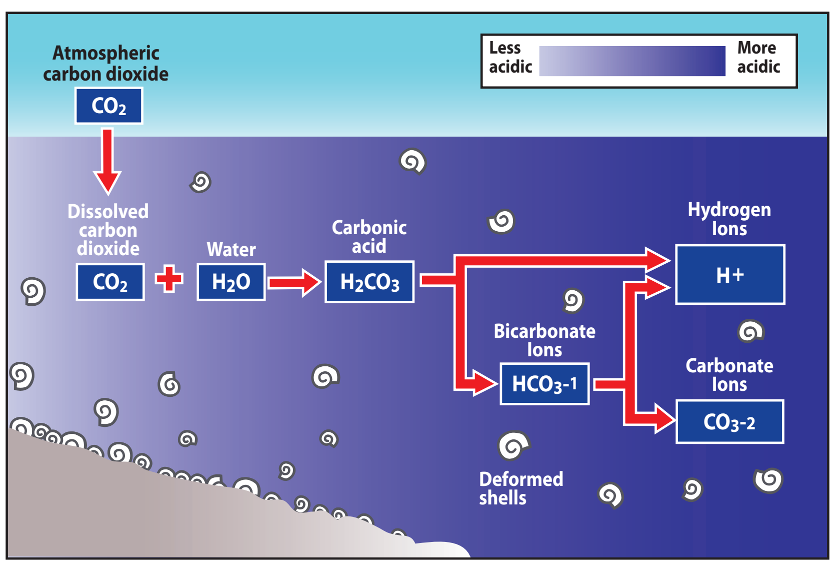


Figure 2. Ocean acidification. **The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms. As more carbon dioxide is absorbed from the atmosphere, oceans will become more acidic.**

flexible in order to adapt to climate change impacts and maintain resource sustainability in the future[4]. Currently, the Oregon Department of Fish and Wildlife is working with a number of conservation partners to support ongoing efforts and develop new methods to conserve the ecological value of subtidal habitats in the face of various stressors, including climate change.
These include:

- developing an inventory of Oregon's subtidal soft-bottom areas and rocky reefs to establish a baseline of habitat distribution, physical structure, and depth;
- periodic monitoring of species on rocky reefs to understand the changes in abundance associated with natural cycles and harvest;
- conducting gear selectivity and bycatch reduction studies to reduce fishing impacts on subtidal communities;
- generating baseline data to understand the resources present;
- collecting socioeconomic data to understand the relationship between coastal communities and nearshore resources, and using it to inform decision-making; and
- monitoring the influence of ocean conditions on long-term trends in abundance.

These efforts represent large scientific questions that cannot be addressed with individual research projects. As resource managers learn more about the effects of climate change on subtidal communities, that knowledge can be applied to the cumulative effects on habitats and organisms from multiple impacts that occur simultaneously. Management approaches must then adapt to best address these effects. Adaptive management is based on an understanding of environmental processes, and an acceptance of large-scale changes that can be addressed by increasing ecological resilience[32].

Species responses to short-term changes in environmental conditions need to be documented in order to predict how local populations are likely to respond when exposed to large-scale or long-term climate change impacts[32]. Understanding these variables will continue over time by building the region's research base and emphasizing nearshore research. Informed by the results of ongoing research and collaborative efforts, management strategies can be designed to reduce existing sources of stress on subtidal habitats and the fish and wildlife that utilize them. By minimizing existing impacts, future threats to subtidal habitats can be moderated and nearshore communities can better cope with climate change and other current and future threats.

Kelp beds on Oregon's south coast. ODFW photo.

Kelp blades. ODFW photo.

Kelp Beds and Climate Change

Kelp beds are extremely productive and diverse, supporting many species of fish, shellfish, bryozoans, sponges, and tunicates[12]. Kelp beds are particularly sensitive to high temperatures and low nutrient levels, making them vulnerable to some of the climate change impacts already observed in Oregon's nearshore subtidal habitats[4].

In Oregon's nearshore, kelp beds only form on rocky substrate located in shallow subtidal areas[1,12]. At depths greater than ~ 80 feet (25 meters), low light levels on the seafloor limit the growth of kelp[1]. Natural factors that may limit the growth of kelp in shallow waters include seasonal sand burial of the reef, sand scour of the rocks, too much wave and storm exposure, locally high turbidity, the amount of exposure to nutrient-rich waters, abundance of organisms that eat kelp (e.g., sea urchins), and competition with attached invertebrates and algae for rock surface[1,12]. All of these limiting factors can be exacerbated by climate change.

Kelp stalks are anchored to subtidal rocks by a holdfast, which is connected by a stipe to the blades. Blades fan out near the water's surface forming a canopy and eventually producing sporophytes for reproduction. When shallow rocky areas receive cold, nutrient rich water through upwelling, holdfasts and canopies grow larger and more sporophytes are produced, dramatically increasing the stability and successful growth of the population[33]. Sporophytes travel through the water and settle in new shoreline habitats, but will only successfully attach and grow on hard substrates like rocky reefs[12]. As waters warm and nutrient delivery from upwelling and oceanic circulation becomes more variable, conditions for kelp forests will likely deteriorate and may result in population declines. If kelp beds decline, subtidal species reliant on kelp for food and habitat will be affected.

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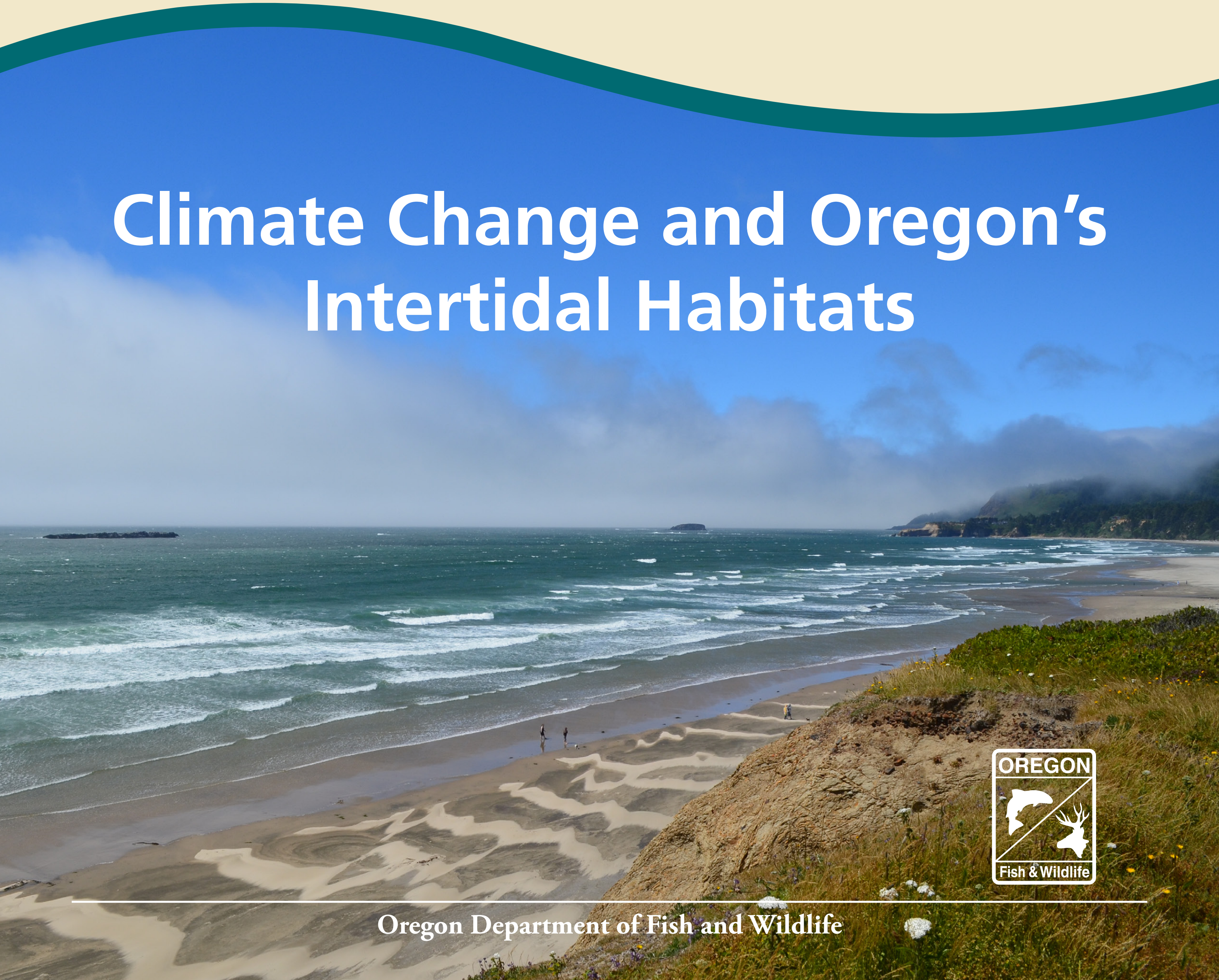


Climate Change and Oregon's Intertidal Habitats

Oregon Department of Fish and Wildlife

Oregon's intertidal habitats include the sandy beaches and rocky areas between extreme high tide and extreme low tide. Differences in elevation, degree of wave exposure, and type of geologic structure within these habitats produce a variety of microhabitats, often supporting high species diversity within relatively small geographic areas[1]. The physical environment changes dramatically as the tide rises and falls, subjecting organisms to constant variations of exposure to air, waves, freshwater and sun. Local currents and ocean circulation introduce additional variables to the habitat, including sand scour of rocks, seasonal burial of rocky areas, and transport of food, larvae, and nutrients to and from intertidal sites. Seasonal variation in wind, wave energy and currents move substantial amounts of sand onto or away from the intertidal zone, resulting in significant changes in habitat characteristics throughout the year.

Species living in the intertidal environment have adapted in a variety of ways to survive these frequently changing conditions. Some move to follow the level of water as the tide rises and falls, or seek shelter in shaded crevices or beneath seaweed. Others retain water within shells and bodies, burrow, or rely on specialized abilities for orientation and picking up environmental cues. The adult stages of many intertidal species are unique to these habitats, although these species commonly have larval stages that inhabit open water habitats. Intertidal areas provide many benefits including:

- beach storage of sand for alongshore transport;
- resting, feeding and refuge areas for birds and marine mammals;
- absorption of wave and storm surges, buffering the coastline against storm damage; and
- nursery areas and seagrass beds that support early development of marine species.

Intertidal areas attract substantial human use for activities such as walking, wildlife watching and tidepooling. Some beaches serve as launch and recovery areas for surfers, personal watercrafts and fishing boats. Visitation of the intertidal area has been increasing, leading to increased harmful impacts from trampling of marine organisms and degradation of habitat. Development in coastal areas has led to alteration or loss of intertidal habitats. The rise of atmospheric carbon dioxide will bring new threats and may exacerbate existing impacts to Oregon's intertidal habitats and species.

Consequences of Increased Carbon Dioxide for Oregon's Intertidal Areas

Rising atmospheric carbon dioxide is causing a variety of impacts on the marine environment, including altered ocean circulation, increasing sea temperatures, sea level rise, changing weather patterns, and changes in freshwater input and ocean chemistry[2]. As intertidal habitats change, individual fish and wildlife species will respond in different ways to these environmental changes. Intertidal species may experience diminished food supply, decreased reproductive success, changes in distribution, habitat alteration, or other effects.

Changes in Oceanic Cycles

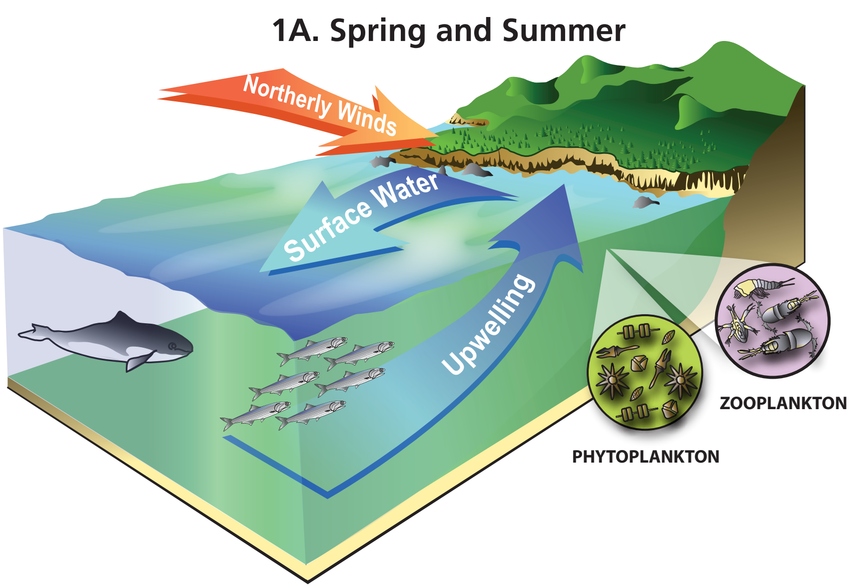
Oregon's nearshore ocean is constantly changing, making it challenging to sort out signals of climate change impacts from other environmental cycles. The relationship between each of these cycles and rising carbon dioxide levels is not well understood. Understanding how oceanic cycles function is a necessary first step to understanding how climate change may alter the nearshore environment.

Climate change may alter the patterns of seasonal upwelling and downwelling that make up the annual cycle (Figure 1). Upwelling is the wind-driven circulation of cold, nutrient-rich water from deep in the ocean up to nearshore waters in the spring and summer. Downwelling is the movement of warmer, oxygen-rich surface water from the nearshore to deeper waters during fall and winter. As the climate warms, the alongshore winds that drive this cycle may grow stronger, therefore intensifying upwelling[3]. As a consequence of climate change, predictions suggest that the spring transition from downwelling to upwelling conditions will be delayed and followed by stronger upwelling later in the season[4,5].

Cover Photos: ODFW

Both upwelling and downwelling are important to maintaining the base of the marine food web, annual productivity, and species diversity. When the delivery of nutrient-rich bottom water is delayed, primary production of marine algae and phytoplankton are also postponed[5]. Delayed or low levels of primary productivity may not support many intertidal organisms for which food availability is time-sensitive[5]. Intertidal species may suffer low recruitment during intense, late-season upwelling periods. Upwelling phases of surging and relaxing transfer fish and invertebrate larvae between the shoreline and offshore waters. If upwelling continues for extended periods without relaxation, larvae are forced to stay in offshore waters where they will not settle and grow in appropriate intertidal habitat.

Upwelling events decrease summer sea temperatures by bringing cold water to the nearshore. Shoreline conditions tend to be foggy and cool during upwelling events, easing the stresses to intertidal organisms during low tides[3,6]. Key invertebrate predators including sea stars and whelks are most densely populated during the upwelling season[7]. When upwelling brings cold water into the nearshore, the decreased water temperatures slow the metabolic rate of these animals causing them to consume far less prey[7]. If Oregon's characteristic seasonal water temperatures are changed, warmer water temperatures in the spring could have significant impacts on intertidal community relationships and predator-prey interactions[6,7].



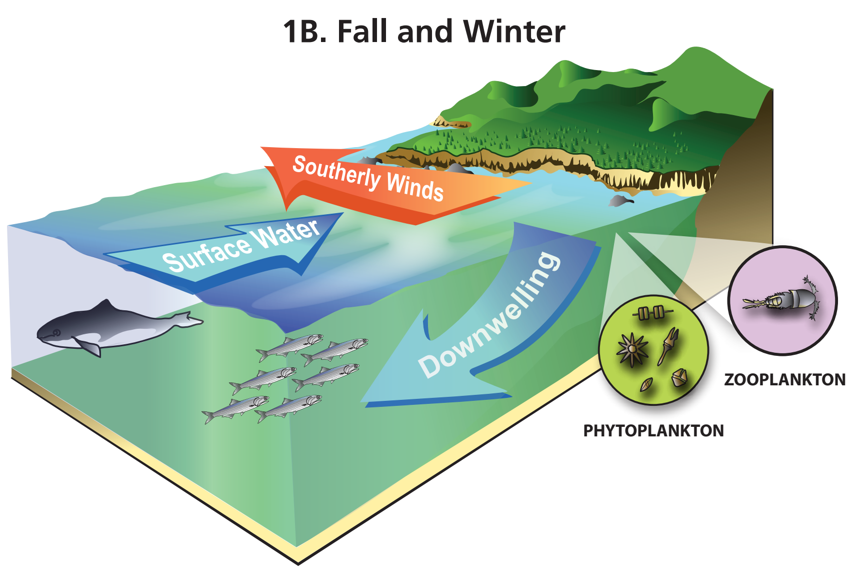


Figure 1. Upwelling and Downwelling

1A. During spring and summer, winds from the north blow parallel to the shore, exerting drag on the ocean's surface. The combination of energy transfer downward in the water column and the earth's rotation move surface waters off shore, 90 degrees to the right of the wind direction. This water is replaced by cold, nutrient rich, low oxygen waters from the deep offshore ocean. This process is called upwelling. During spring/summer, upwelling production of nearshore plants and animals is at its highest.

1B. During fall and winter, winds from the south blow parallel to the shore driving surface waters shoreward where they submerge in a process called downwelling. Downwelling transports nearshore surface waters to resupply deep offshore waters with oxygen. Storm activity is highest, and runoff from precipitation over land contributes to mixing nearshore waters and loading the environment with oxygen and freshwater inputs.

Warming Ocean Temperatures

The world's oceans are warming. For most of the past century, significant changes in sea surface temperatures have been recorded in the northeast Pacific[8] as most of the added heat to the atmosphere is absorbed by the ocean[9]. Oregon's coastal surface waters have warmed an average of 0.5° F (0.3° C) per decade since mid-20th century and are predicted to increase an average of 2.2° F (1.2° C) by the mid-21st century[10]. Warming conditions affect intertidal community dynamics in many ways including shifts in species distribution towards the poles and altered growth of marine organisms[11,12].

Organisms respond to climate change by relocating to microhabitats with preferred conditions. As ocean temperatures warm, distributions of fish populations and other mobile animals are moving northward, likely associated with specific temperature requirements[12,13]. These species distribution shifts may be linked to the availability of food sources that require specific temperatures[12,13]. Attached rocky intertidal animals may be affected more by changes in terrestrial temperatures than water temperatures[6]. For many of them, increased heat stress and exposure may limit species range or reduce local populations[8,14].

Some species, such as mussels, will grow larger or faster due to an accelerated metabolic response to warmer water temperatures[14]. However, at some point, the ability of marine species to take advantage of warmer water temperatures will exceed its tolerance, resulting in death[15]. Species experiencing rapid growth will run out of suitable habitat more quickly, beyond which point growth is limited by the animals' tolerance to warmer temperatures and exposure to air at low tide[14].

Sea Level Rise

Sea level is rising due to melting ice sheets and expanding sea water, both consequences of rising global temperatures. As a result, small islands may soon be submerged, leading to a loss of intertidal habitat[11]. Along the shoreline, the high-tide line is migrating inland, forcing beach habitat to move inland or be compressed between cliffs or developed shoreline structures and the rising sea level[16]. Habitat changes associated with sea level rise are particularly pronounced in areas with beach armoring (structures that have been built to control shoreline erosion). As these structures come in contact with high-energy waves more often, beach erosion will be accelerated[16]. Beach sediment distribution will be altered, leading to habitat changes such as beach slope and grain size[17].

Sea level rise may correspond to modified reproductive timing or success for marine beach-spawning populations[17]. For example, two key marine prey species that spawn on intertidal beaches–surf smelt and Pacific sandlance–will lose significant spawning habitat in the coming decades as beaches are compressed and environmental conditions appropriate for reproduction are altered by climate change[17]. Without certain conditions (e.g., temperature, humidity, elevation, light exposure) survival of young will be substantially reduced [17,18].

As sea levels rise, intertidal habitats and species interactions are altered dramatically in terms of

California mussels at Bob's Creek, Cape Perpetua. ODFW photo.

distribution, competition and predation[6,14]. Rising sea levels will reduce the availability and suitability of beach haulout sites for harbor seals[15]. Decreased densities of intertidal crabs are associated with sea level rise[19]. The upper range of the California mussel continues to expand upwards as sea levels rise, competing with other attached invertebrates for space[14]. The range of a key predator, the ochre sea star, is also expanding, increasing predation rates on attached intertidal invertebrates[14]. The ability of intertidal animals to adapt to sea level rise will depend on the availability of suitable habitat at higher elevations that will gradually be converted from upland to intertidal area [6].

Harbor seals using sandy beaches. ODFW photo.

Ochre sea stars consuming California mussels. David Cowles photo.

Coastal Storms and Wave Height

Storm intensity and wave heights have increased off the west coast during the past 50 years[20]. As a result, greater erosion of shoreline habitats has been caused by increased wave action and more turbulent waters washing the beach[20]. Both storm intensity and wave height may be linked to rising water temperatures, and the capacity for storms to carry heat, precipitation, and surface winds northward is intensified by climate change[21]. As seawater warms, heat energy builds and can result in storms with greater intensity, longer duration, earlier annual fall onset, and a larger total area affected[22]. As storms intensify, so does the amount of wave energy approaching the shore from different directions, which can accelerate erosion of sandy beach habitats[23].

Changes in storm activity or wave height may alter physical characteristics of sandy beaches such as slope and sand grain size, which are the primary factors determining the abundance and species composition of sandy beach communities[16,24]. Gentle-slope sandy beaches are subjected to the highest extent of wave run-up. These areas support some of the most diverse beach communities and are particularly vulnerable to erosion and redistribution of sand. Loss of these beaches will squeeze many invertebrate species between steep upland areas and rising sea levels. These species will suffer reduced ability to colonize beaches and will be increasingly subjected to high-energy storms and waves[16,24,25].

Changes in Freshwater Input

Climate change will alter frequency, magnitude and duration of freshwater inputs into the nearshore ocean. As Oregon's climate warms, winter and spring flooding may increase while summer and fall precipitation may diminish. This would lead to higher seasonal extremes in the amount of freshwater versus saltwater in nearshore ocean waters, affecting nearshore habitats and species. The amount of freshwater input changes the salinity and density of seawater. Changes in freshwater input may alter nearshore circulation and affect the availability of nutrients in the nearshore ocean.

Changes in freshwater inputs to Oregon's nearshore ocean will affect intertidal species compositions and distributions. Freshwater rivers that cross sandy beaches to flow into nearshore waters can become "bar-bound" during low-flow periods in summer and fall, forcing the river to flow through the sand to reach the sea. When this happens, changes occur to the amount of water, nutrients, and sometimes pollutants present in sandy beach habitats, affecting resident organisms.

Flooding of freshwater systems can increase erosion of riparian and estuarine sediments. These changes will have direct impacts on the sediment structure and availability of light in nearshore habitats[8]. Sessile invertebrates, such as barnacles or mussels, would be directly affected when buried by high levels of sediment delivered by nearby freshwater sources. Altered nearshore circulation will impact the distribution of organisms that drift in nearshore waters[26] and eventually settle on intertidal rocks or sand.

Ocean Acidification

The world's oceans are becoming increasingly acidic as more atmospheric carbon dioxide is absorbed into the ocean[10,12,27]. Seawater contains carbonate ions that are necessary for skeleton and shell formation. However, when carbon dioxide is absorbed by the ocean, the availability of carbonate is reduced (Figure 2) and successful development of mussels, barnacles, clams, corals, and planktonic food sources that support fisheries, including salmon and groundfish, is threatened[10,22,27].

Shell-forming organisms may suffer reduced individual size and decreased populations as seawater becomes more acidic[12]. Organisms living on or beneath the sandy surface are also vulnerable to impacts of acidification. Marine organisms respond differently to acidification at local scales, particularly in nearshore waters, where the characteristics of the water are most variable[28]. Tidepool conditions change naturally between high and low levels of oxygen and carbon dioxide as animals breathe and incoming tides flush the pools[29,30]. However, as acidic waters increasingly impact intertidal habitats, resident organisms may need to adapt by making costly trade-offs to stay alive[29]. Animals may experience disruption to normal chemical cues in the water and become disoriented, causing them to compromise reproductive success or make themselves more vulnerable to predators[29]. For example, as hermit crabs grow out of their shells and search for larger replacements, the decision making process may be affected by acidification, which reduces the ability of hermit crabs to select optimal shells[29].

Species interactions and predation dynamics are expected to change under acidic conditions, leading to reduced species diversity and changes in community structure[29,31]. The effects of water temperature and acidity can interact to produce complex species responses that impact community abundance and diversity[31]. For example, mollusks showed the greatest reduction in abundance and diversity in response to more acidic and warmer waters, whereas nematodes increased in response to the same conditions, probably due to a reduction in predation and competition[31]. Acidification can alter competition among species and predation behaviors, contributing to increased populations of algae and organisms that don't develop shells[12]. Each time the abundance of a single species is changed, there is a possibility of cascading effects throughout the intertidal community.

Managing for Climate-adaptive Intertidal Areas

Intertidal marine species are subject to a host of stressors including habitat alteration and coastal development. Climate change impacts will add to these pressures in the coming years, putting additional strain on marine ecosystems[22]. Many aspects of climate change impacts on nearshore marine systems remain poorly understood. More information is needed regarding large-scale or long-term environmental variability and rates of change. Additional information pertaining to the relationships between ocean circulation, local habitats, marine populations, and human uses will help inform future management actions. Cooperative research and evaluation of threats to marine ecosystems, including climate change, could help bridge data gaps and overcome a limited understanding of all impacts to intertidal habitats and species[32]. Oregon's intertidal areas are publicly owned,

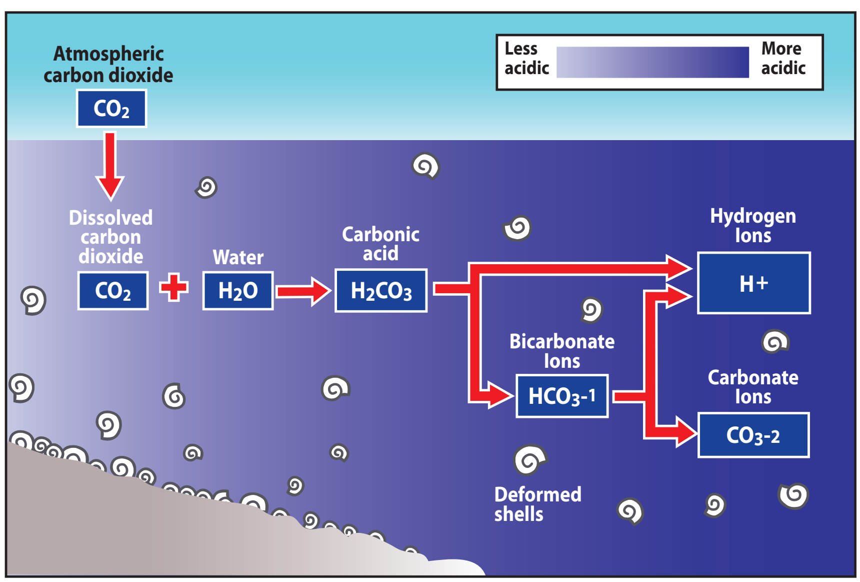


Figure 2. Ocean acidification
The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms.
As more carbon dioxide is absorbed from the atmosphere, oceans will become more acidic.

ODFW personnel sampling clams in rocky cobble intertidal habitat. ODFW photo.

resulting in a complex mix of laws, rules and programs governing the use, conservation and management of Oregon's marine resources[1]. Management of marine resources should be flexible in order to adapt to climate change impacts and maintain resource sustainability in the future[15]. Currently, the Oregon Department of Fish and Wildlife is working with a number of conservation partners to support ongoing efforts and develop new methods to conserve the ecological value of intertidal habitats in the face of various stressors, including climate change. These include:

- assessing the effects of beach armoring structures on natural sediment migration;
- managing harvest of marine intertidal species;
- educating the public about tidepool and beach etiquette, and encouraging a sense of personal stewardship;
- enhancing nearshore research and monitoring programs and developing new programs to meet data needs for conservation and management;
- generating baseline data to understand the resources present; and
- determining the influence of ocean conditions on long-term recruitment and survival, and monitoring long-term trends in population size.

These efforts represent large scientific questions that cannot be fully addressed with individual research projects. As resource managers learn more about the effects of climate change on intertidal communities, that knowledge can be applied to the cumulative effects on habitats and organisms where multiple impacts are occurring simultaneously. Management approaches must then adapt to best address these effects. Adaptive management is based on an understanding of environmental processes, and an acceptance of large-scale changes that can be addressed by increasing ecological resilience[16].

Oregon's intertidal habitats are occupied by specialized organisms that are well adapted to high-energy and highly changeable environments[16]. Species responses to short-term changes in environmental conditions need to be documented in order to predict how local populations are likely to respond when exposed to large-scale or long-term climate change impacts[16]. Understanding these variables will continue over time by building the region's research base and emphasizing nearshore research. Informed by the results of ongoing research and collaborative efforts, management strategies can be designed to reduce the existing sources of stress on intertidal habitats and the fish and wildlife that utilize them. By minimizing existing impacts, future threats to intertidal habitats can be moderated and nearshore communities can better cope with climate change and other current and future threats.

Harmful Algal Blooms and Climate Change

Within the past 15 years, harmful algal blooms have been on the rise[15], and although they occur in open water, from the human perspective, their effects are generally observed in the intertidal. Altered ocean circulation, warming sea temperatures and changes in freshwater inputs and ocean chemistry resulting from climate change may be increasing harmful algal blooms.

When chemical or physical water properties are changed, algae productivity will change either producing insufficient biomass to support local populations, or overproducing to the extent that systems become polluted[15]. As upwelling patterns are disrupted, the timing and strength of transport of cold, nutrient-rich oceanic waters to the nearshore may be altered[15]. This infusion of water is responsible for highly productive algal blooms that occur in the nearshore during the summer[15]. These naturally occurring blooms drive marine food webs in Oregon. As surface waters warm, wind-driven circulation of ocean waters may be insufficient to maintain normal chemical composition of nearshore waters[15]. At the same time, changes in freshwater input may increase nutrient input, further contributing to toxic algal blooms[33].

Phytoplankton and algae form the base of intertidal marine food webs and produce the food and energy required to sustain life in nearshore waters[15]. Some species produce domoic acid, a toxin that accumulates in intertidal shellfish and can induce amnesic shellfish poisoning in humans[15]. Other species can produce the toxin responsible for paralytic shellfish poisoning in humans[34]. In 2009, the widespread algal bloom on northern Oregon coast dissolved the oils in seabird feathers necessary for heat retention, resulting in a significant die-off of seabirds[15]. Increasing harmful algal blooms may translate to ecosystem, economic, and/or human health concerns[15].

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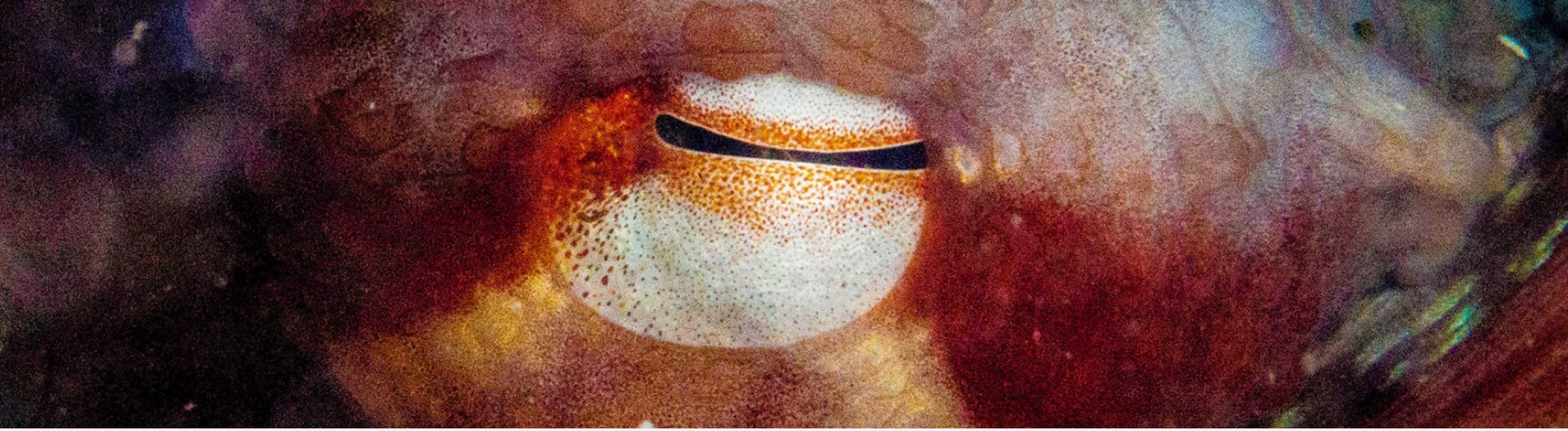

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NEARSHORE APPENDICES E - G

NEARSHORE APPENDIX E: WATCH LIST SPECIES HABITAT ASSOCIATIONS

Watch List Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Habitat Unknown	Comments
Brandt's Cormorant *Phalacrocorax penicillatus*	X		X	X	X	X		Utilizes rocky cliffs and islands for nesting. Forages in nearshore habitats.
Cassin's Auklet *Ptychoramphus aleuticus*	X			X				Nests in burrows on offshore islands with no mammalian predators.

Watch List Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Habitat Unknown	Comments
Common Murre *Uria aalge*	X		X	X	X	X		Central place forager while nesting in colonies on rocky headlands and offshore islands. Can dive deeply while foraging
Pelagic Cormorant *Phalacrocorax pelagicus*	X		X		X			Utilizes rocky cliffs and islands for nesting. Forages in nearshore habitats.
Pigeon Guillemot Cepp*hus columba*	X		X	X	X			Nests in burrows or crevices. Forages in nearshore habitats.
Sanderling *Calidris alba*		X						Forages in intertidal areas during migration.
Rhinocerous Auklet *Cerohinca monocerata*	X				X			Nests in burrows on offshore islands. Forages in nearshore waters while nesting.
Black-and-yellow rockfish *Sebastes chrysomelas*	X		X		X			Spawning not known to occur in OR waters. Juveniles not known to occur over soft bottom habitats in OR.
Blue shark *Prionace glauca*					X			Predominately found offshore.
Bocaccio *Sebastes paucispinis*			X	X	X	X	X	
Brown Irish lord Hemilepidotus spinosus	X		X					Mid to low intertidal.
Brown smoothhound Mustelus henlei				X		X		Found from Coos Bay to Gulf of CA. Schooling fish.
Buffalo sculpin *Enophrys bison*			X	X				Usually found inshore.

Watch List Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Habitat Unknown	Comments
Butter sole *Isopsetta isolepis*				X				
California halibut *Paralichthys californicus*				X				Usually near structures: rocks, holdfasts, etc.
California skate *Raja inornata*				X		X		
Common thresher *Alopias vulpinus*					X			Likely to be highly migratory.
Curlfin turbot (sole) *Pleuronichthys decurrens*				X				Also called Curlfin sole; true turbots native to North Atlantic and Mediterranean.
English sole *Parophrys vetulus*		X		X		X		Juveniles found predominately nearshore. Adults found predominately offshore.
Flathead sole *Hippoglossoides elassodon*				X				
Giant wrymouth *Cryptacanthodes giganteus*				X				
Gopher rockfish *Sebastes carnatus*	X		X	X	X			Will inhabit artificial reefs. Pelagic juveniles not known to occur in OR waters. Spawning and larvae not known to occur in OR.
Leopard shark Triakis semifasciata			X	X		X		Schooling fish. Predominately found nearshore.
Monkeyface pricklepack *Cebidichthys violaceus*	X		X					High, mid, and low intertidal. Tidepools and shallow subtidal. Jetties and breakwaters. Central OR is northern extent of range.

Watch List Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Habitat Unknown	Comments
Pacific angel shark *Squatina californica*			X	X				Uncommon north of CA.
Pacific sanddab *Citharichthys sordidus*				X		X		
Pacific sandfish *Trichodon trichodon*				X				
Pacific sardine *Sardinops sagax*					X			Schooling fish. Occurs offshore.
Pacific staghorn sculpin *Leptocottus armatus*		X		X		X		Most common in estuaries. Recently hatched fish often recruit into fresh water for a short time.
Red Irish lord *Hemilepidotus hemilepidotus*	X		X					Mid to low intertidal. Wharves and pilings.
Rock sole *Pleuronectes bilineatus*				X				Prefers sandy or gravel bottoms.
Salmon shark *Lamna ditropis*					X			
Sand sole *Psettichthys melanostictus*				X				
Shortfin mako (Bonito) shark *Isurus oxyrinchus*					X			Predominantly found offshore.
Soupfin shark *Galeorhinus galeus*				X	X			Schooling fish. Females found shallower than males.
Southern rock sole *Lepidopsetta bilineata*			X	X		X		Pebble or semi-rocky bottom. Also occurs offshore.

Watch List Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Habitat Unknown	Comments
Spotted ratfish *Hydrolagus colliei*			**X**	**X**				Common in shallower waters in northern part of range.
White shark *Carcharodon carcharias*					**X**		**X**	
Butter clam Saxidomus gigantea						**X**		
California sea cucumber *Parastichopus californicus*			**X**	**X**				Generally prefers protected areas.
Cockle clam *Clinocardium nuttallii*						**X**		
Coonstripe (Dock) shrimp *Pandalus danae*			X	X				
Fat gaper clam *Tresus capax*						**X**		
Flat-tipped piddock *Penitella penita*	**X**		**X**					Mid to low intertidal. Commonly bores into stiff clay, sandstone, shale, and concrete.
Market squid *Doryteuthis opalescens*				**X**	**X**			School and spawn on muddy sand in shallow, protected, inshore areas.
Oregon triton *Fusitriton oregonensis*			**X**	**X**				Occasionally intertidal.
Pacific sand (mole) crab *Emerita analoga*		**X**						Mid and low intertidal.
Red rock crab *Cancer productus*				**X**		**X**		
Sea otter *Enhydra lutris*			**X**		**X**			Sporadic visitors to Oregon.

NEARSHORE APPENDIX F: OTHER/COMMONLY ASSOCIATED SPECIES LIST

<u>**Appendix F**</u>**.** Commonly associated species and habitats found in Oregon's nearshore environment.

Species	Habitat Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Unknown	Comments
Birds								
California gull *Larus californicus*					X	X		
Glaucous-winged gull *Larus glaucescens*	X	X			X	X		Colonial nester.
Pacific loon *Gavia pacifica*					X	X		Winters near coastal waters.
Red-necked phalarope *Phalaropus lobatus*					X			Concentrates around oceanic upwellings and edges of kelp beds.
Red throated loon *Gavia stellata*					X	X		Winters near coastal waters.
Sooty shearwater *Puffinus griseus*					X			Concentrates around oceanic upwellings and over the continental shelf.
Surf scoter *Melanitta perspicillata*					X	X		
Western gull *Larus occidentalis*	X	X			X	X		Colonial nester.
Western grebe *Aechmophorus occidentalis*						X		
White-winged scoter *Melanitta fusca*				X	X	X		Common in shallow water over shellfish beds.

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

	Habitat							
Species	**Rocky Shore**	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Fishes								
Bald sculpin *Clinocottus recalvus*	X		X					Tidepools. Shallow subtidal. Brookings, OR is northern extent of range
Bat ray *Myliobatis californica*		X	X	X	X			Low intertidal.
Black prickleback *Xiphister atropurpureus*	X		X					Under rocks, in gravel areas. Shallow subtidal
Bonehead sculpin *Artedius notospilotus*	X		X					
Calico sculpin *Clinocottus embryum*	X							Mid to low intertidal.
Calico surfperch *Amphistichus koelzi*		X		X				Shallow subtidal.
Coralline sculpin *Artedius corallinus*	X		X					Shallow subtidal.
Crescent gunnel *Pholis laeta*	X		X					Tidepools.
Decorated warbonnet *Chirolophis decoratus*			X					Usually among algae.
Fluffy sculpin *Oligocottus snyderi*	X		X					Tidepools. Shallow subtidal. Often in algae.
Grunt sculpin *Rhamphocottus richardsonii*	X		X	X				Tidepools.

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

Species	Habitat: Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Unknown	Comments
High cockscomb *Anoplarchus purpurescens*	X		X					Usually intertidal.
Jacksmelt *Atherinopsis californiensis*			X		X	X		Yaquina Bay, OR is northern extent of range.
Kelp poacher *Agonomalus mozinoi*			X					Shallow subtidal.
Kelp surfperch *Brachyistius frenatus*			X					
Longfin gunnel *Pholis clemensi*			X					
Longfin sculpin *Jordania zonope*	X		X					
Lumptail searobin *Prionotus stephanophrys*				X				Deep subtidal.
Manacled sculpin *Synchirus gilli*	X		X					Tidepools.
Mosshead sculpin *Clinocottus globiceps*	X		X					Tidepools. Shallow subtidal.
Mosshead warbonnet *Chirolophis nugator*			X					
Night smelt *Spirinchus starksi*		X			X			Spawn on beaches.
Northern clingfish *Gobiesox maeandricus*	X		X					Shallow subtidal.

<u>Appendix F</u>. Commonly associated species and habitats found in Oregon's nearshore environment.

	Habitat							
Species	**Rocky Shore**	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Pacific electric ray *Torpedo californica*			X	X				
Pacific hooker (Hookhorn) sculpin *Artediellus pacificus*				X				
Padded sculpin *Artedius fenestralis*	X		X					Shallow subtidal.
Painted greenling *Oxylebius pictus*	X		X					Shallow subtidal.
Penpoint gunnel *Apodichthys flavidus*	X							Tidepools and in algae.
Pricklebreast poacher *Stellerina xyosterna*				X				
Puget Sound sculpin *Ruscarius meanyi*	X		X					
Pygmy poacher *Odontopyxis trispinosa*				X				
Red brotula *Brosmophycis marginata*			X					
Red gunnel *Pholis schultzi*	X		X					Shallow subtidal. Exposed surge areas.
Ribbon prickleback *Phytichthys chirus*	X		X					Shallow subtidal.

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

	Habitat							
Species	**Rocky Shore**	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Rock prickleback *Xiphister mucosus*	X		X					Intertidal, found among algae. Shallow subtidal.
Rockhead *Bothragonus swanii*	X		X					Shallow subtidal.
Rockweed gunnel *Apodichthys fucorum*	X		X					Common among algae in tidepools and shallow subtidal.
Rosylip sculpin *Ascelichthys rhodorus*	X		X					Tidepools.
Roughback sculpin *Chitonotus pugetensis*		X		X				
Saddleback gunnel *Pholis ornata*				X				
Saddleback sculpin *Oligocottus rimensis*	X		X					Tidepools in low intertidal.
Sailfin sculpin *Nautichthys oculofasciatus*			X	X				Pilings. Soft bottoms near rubble.
Scalyhead sculpin *Artedius harringtoni*	X		X					Shallow subtidal. Pilings.
Sharpnose sculpin *Clinocottus acuticeps*	X		X	X				Shallow subtidal.
Sharpnose surfperch *Phanerodon atripes*			X					
Silver surfperch *Hyperprosopon ellipticum*			X	X				Surf zone down to deep subtidal.

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

Species	**Habitat**							
	Rocky Shore	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Silverspotted sculpin *Blepsias cirrhosus*	**X**		**X**					Often among algae.
Slender cockscomb *Anoplarchus insignis*			**X**					
Smooth alligatorfish *Anoplagonus inermis*			**X**					
Smoothhead sculpin *Artedius lateralis*	**X**		**X**					Shallow subtidal.
Snake prickleback *Lumpenus sagitta*					**X**	**X**		
Speckled sanddab *Citharichthys stigmaeus*				**X**				
Spotfin surfperch *Hyperprosopon anale*				**X**				Surf zone down to deep subtidal.
Sturgeon poacher *Podothecus accipenserinus*				**X**				Deep subtidal.
Tidepool sculpin *Oligocottus maculosus*	**X**							Tidepools.
Tubenose poacher *Pallasina barbata*	**X**		**X**					Often among algae.
Tubesnout *Aulorhynchus flavidus*			**X**	**X**				
Walleye surfperch *Hyperprosopon argenteum*			**X**	**X**	**X**			Shallow subtidal. Artificial reefs and pilings.

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Unknown	Comments
					Habitat			
White surfperch *Phanerodon furcatus*			X	X	X	X		Artificial reefs, pilings, and docks.
Whitebait smelt *Allosmerus elongatus*					X	X		
Y-prickleback *Lumpenopsis hypochroma*							X	
Marine Mammals								
California sea lion *Zalophus californianus*	X	X	X	X	X	X		Males seasonally migrate to Oregon.
Invertebrates								
Acorn barnacle *Sessilia spp.*	X							Low intertidal.
Aggregating anemone *Anthopleura elegantissima*	X					X		Mid intertidal.
Barnacle *Chthamalus spp.*	X							High and mid intertidal. Common on rocks and pier pilings.
Black katy chiton *Katharina tunicata*	X							Mid to low intertidal. Areas of strong wave action.
Brown rock crab *Cancer antennarius*	X		X	X				Low intertidal. Soft bottom; gravel.
Channeled dog winkle (Whelk) *Nucella canaliculata*	X							Mid intertidal. Common on rocks and in mussel beds.

<u>Appendix F</u>. Commonly associated species and habitats found in Oregon's nearshore environment.

	Habitat							
Species	**Rocky Shore**	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Cockle clam *Clinocardium nuttallii*		X		X		X		Low intertidal.
Fingered limpet *Lottia digitalis*	X							High intertidal.
Giant green anemone *Anthopleura xanthogrammica*	X		X			X		Low intertidal.
Gooseneck barnacle *Pollicipes polymerus*	X							Mid intertidal. Sometimes mixed with California mussels (*Mytilus californianus*)
Gumboot chiton *Cryptochiton stelleri*	X		X					Low intertidal.
Hermit crabs *Pagurus spp.*	X		X	X				High and low intertidal. Tidepools. Rock and gravel bottoms subtidally.
Kelp crab *Pugettia producta*	X		X					Low intertidal of protected outer coast.
Keyhole limpet *Diodora aspera*	X							Low intertidal.
Newcomb's littorine snail *Littorina subrotunda (Algamorda newcombiana)*	X							High intertidal.
Nudibranchs Nudibranchia	X		X					Low intertidal.
Pacific sand dollar *Dendraster excentricus*				X		X		

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

							Habitat	
Species	**Rocky Shore**	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Pinto (Northern) abalone *Haliotis kamtschatkana*	X		X					Low intertidal.
Porcelain crab *Petrolisthes cinctipes*	X							Mid to low intertidal.
Purple shore crab *Hemigrapsus nudus*	X					X		Mid to low intertidal.
Rock dwelling purple whelk *Nucella emarginata*	X							High to mid intertidal. Often among mussel beds and barnacles.
Sabellid worm *Myxicola infundibulum*				X		X		
Shield limpet *Lottia pelta*	X		X					Mid to low intertidal.
Sponges Porifera	X		X					
Spot prawn *Pandalus platyceros*	X		X	X	X			Low intertidal to 487 m. Larvae are planktonic.
Tube worm *Neosabellaria cementarium*	X		X					Low intertidal.
Turban snails *Tegula spp.*	X		X					Low intertidal.
Upper intertidal barnacle *Balanus glandula*	X					X		High to mid intertidal.
Wrinkled amphissa *Amphissa columbiana*	X		X					Low intertidal.

<u>Appendix F</u>. Commonly associated species and habitats found in Oregon's nearshore environment.

	Habitat							
Species	**Rocky Shore**	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Wrinkled purple whelk *Nucella lamellosa*	**X**							Low intertidal.
Plants and Algae								
Agarophytes & Carrageenophytes *Gelidium spp.*	**X**		**X**					Shallow subtidal.
Agarophytes & Carrageenophytes *Gracilaria sp.*	**X**		**X**			**X**		Low intertidal.
Agarophytes & Carrageenophytes *Gracilariopsis sp.*	**X**		**X**			**X**		Low intertidal.
Agarophytes & Carrageenophytes *Mastocarpus spp.*	**X**							High to mid intertidal.
Agarophytes & Carrageenophytes *Mazzaella spp.*	**X**							
Agarophytes & Carrageenophytes *Pterocladia spp.*	**X**		**X**					Low intertidal, shallow subtidal.
Agarophytes & Carrageenophytes *Sarcodiotheca sp.*	**X**		**X**					Low intertidal. Subtidal on rocks near sandy habitats.

<u>Appendix F</u>. Commonly associated species and habitats found in Oregon's nearshore environment.

Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Unknown	Comments
	Habitat							
Coralline red algae *Bossiella spp.*	X		X					Low intertidal.
Coralline red algae *Calliarthron sp.*	X		X					Low intertidal.
Coralline red algae *Corallina spp.*	X		X					Mid to low intertidal.
Coralline red algae *Lithothamnium spp.*	X							Mid intertidal. Tidepools.
Costaria *Costaria sp.*	X		X					Low intertidal and shallow subtidal.
Dilsea *Dilsea californica*	X		X					Low intertidal.
Dwarf rockweed *Pelvetiopsis limitata*	X							High intertidal.
Endocladia *Endocladia muricata*	X							High intertidal.
Feather boa kelp *Egregia menziesii*	X		X					Low intertidal, shallow subtidal.
Filamentous greens *Enteromorpha*-type	X							High intertidal.
Fucus (Rockweed) *Fucus spp.*	X							Mid to low intertidal.
Giant kelp *Macrocystis pyrifera*			X					

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

Species	Rocky Shore	Sandy Beach	Rocky Subtidal	Soft Bottom Subtidal	Neritic	Estuarine	Unknown	Comments
	Habitat							
Hedophyllum *Hedophyllum sessile*	X							Mid to low intertidal.
Kelp *Macrocystis integrifolia*	X		X					Low intertidal.
Kelp *Laminaria bongardiana*	X		X					
Kelp *Laminaria ephemera*	X		X					
Kelp *Laminaria setchellii*	X		X					
Kelp *Laminaria sinclairii*	X							
Lessoniopsis *Lessoniopsis littoralis*	X							Low intertidal in areas exposed to high surf action.
Odonthalia *Odonthalia spp.*	X							
Pleurophycus *Pleurophycus sp.*	X		X					Low intertidal and shallow subtidal.
Porphyra *Porphyra spp.*	X		X					Intertidal and shallow subtidal.
Prionitis *Prionitis spp.*	X		X					Intertidal and shallow subtidal.
Sea fern *Cystoseira osmundacea*	X		X					Low intertidal and shallow subtidal. Tidepools and on rocks.

Appendix F. Commonly associated species and habitats found in Oregon's nearshore environment.

Species	Habitat							
	Rocky Shore	**Sandy Beach**	**Rocky Subtidal**	**Soft Bottom Subtidal**	**Neritic**	**Estuarine**	**Unknown**	**Comments**
Southern sea palm *Eisenia arborea*	**X**		**X**					Low intertidal.
Stalked kelp *Pterygophora californica*			**X**					
Ulvoids *Ulva spp.*	**X**		**X**					Mid to low intertidal and shallow subtidal.
Winged kelp *Alaria marginata*	**X**		**X**					Low intertidal and shallow subtidal.

NEARSHORE APPENDIX G: NON-NATIVE AND INVASIVE SPECIES

Non-native and invasive species can alter and degrade habitats, increase threats to native species, and in some cases impact local economies or cause extensive problems for marine coastal systems of Oregon. Non-native species can be transported locally, regionally, or around the world and introduced to Oregon's nearshore systems by way of several mechanisms such as, hitch-hiking in ballast water or in ocean currents. Once a species has been introduced it can affect food sources, alter habitats, expose native communities to diseases or toxins, or act as parasites of juvenile and adult members of coastal fisheries species. For many introduced species, the severity of the potential ecological threat is not yet known. Many of these species could be deemed invasive in the future, but further efforts to assess impacts are needed. These efforts are a priority for conservation of natural systems because invasions become more complicated to address over time and management measures that respond to the first arriving individuals are most effective.

Efforts have begun to assess available data regarding existing or potential future threats to Oregon's nearshore and estuarine communities. The Oregon Department of Fish and Wildlife's Marine Resources Program reviewed available online data and consulted with experts at Oregon State University, the Environmental Protection Agency Western Ecology Division, United States Geological Survey Western Fisheries Research Center, and Williams College in 2012 and updated this information in 2015. Based on information gleaned from these sources, a list of non-native species known to occur in the nearshore waters of Oregon and neighboring states was developed. For each species, habitat information was collected and species were identified as being primarily associated with nearshore marine and/or estuarine systems.

Non-Native Species	**Nearshore** [a]	**Estuarine** [b]	**1: OR Invasive** [c]	**2: OR Non-native** [d]	**3: WA or CA Invasive (not known in OR)** [e]
Bony Fishes					
American shad *Alosa sapidissima*	X		X		
Amur goby *Rhinogobius bunneus*	X	X		X	
Atlantic salmon *Salmo salar*	X				X
Brown trout *Salmo trutta*	X				X
Chameleon goby *Tridentiger trigonocephalus*		X			X
Inland silverside *Menidia beryllina*		X			X

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Rainwater killifish *Lucania parva*		X		X	
Shimofuri goby *Tridentiger bifasciatus*		X			X
Shokifaze goby *Tridentiger barbatus*		X			X
Striped bass *Morone saxatilis*	X		X		
Threadfin shad *Dorosoma petenense*	X			X	
Western mosquito fish *Gambusia affinis*		X		X	
Yellowfin goby *Acanthogobius flavimanus*		X			X
Invertebrates					
Acorn barnacle *Amphibalanus improvisus*	X	X		X	
Ambiguous bryozoan *Anguinella palmata*		X			X
American Atlantic sponge *Prosuberites sp.*		X			X
Amethyst gem clam *Gemma gemma*		X			X
Amphipod *Ampelisca abdita*		X			X
Amphipod *Ampithoe lacertosa*	X	X		X	
Amphipod *Ampithoe valida*		X		X	
Amphipod *Chelura terebrans*	X				X
Amphipod *Corophium alienense*		X			X
Amphipod *Eobrolgus spinosus*		X		X	

Non-Native Species	Nearshore[a]	Estuarine[b]	1: OR Invasive[c]	2: OR Non-native[d]	3: WA or CA Invasive (not known in OR)[e]
Amphipod *Ericthonius brasiliensis*		X		X	
Amphipod *Gammarus daiberi*		X			X
Amphipod *Grandidierella japonica*	X	X		X	
Amphipod *Incisocalliope derzhavini*	X			X	
Amphipod *Leucothoe sp.*		X			X
Amphipod *Melita nitida*		X		X	
Amphipod *Melita sp.*		X			X
Amphipod *Microdeutopus gryllotalpa*		X			X
Amphipod *Monocorophium acherusicum*	X	X		X	
Amphipod *Monocorophium insidiosum*	X	X			X
Amphipod *Monocorophium uenoi*		X			X
Amphipod *Paradexamine sp.*		X			X
Amphipod *Parapleustes derzhavini*		X		X	
Amphipod *Ptilohyale littoralis*		X		X	
Amphipod *Sinocorophium heteroceratum*					X
Amphipod *Stenothoe valida*		X			X
Amphipod *Transorchestia enigmatica*					X
Amur River clam *Corbula amurensis*					X

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Asian calanoid copepod *Pseudodiaptomus inopinus*		X		X	
Asian calanoid copepod *Sinocalanus doerrii*		X		X	
Asian clam *Corbicula fluminea*		X	X		
Asian copepod *Acartiella sinensis*		X			X
Asian copepod *Limnoithona sinensis*		X		X	
Asian copepod *Tortanus dextrilobatus*		X			X
Asian cumacean *Nippoleucon hinumensis*		X		X	
Asian lanternshell *Laternula marilina*		X			X
Asian sea-squirt *Styela clava*		X	X		
Asian semele *Theora lubrica*		X			X
Atlantic oyster *Crassostrea virginica*		X			X
Atlantic oyster drill *Urosalpinx cinerea*		X			X
Australasian burrowing isopod *Sphaeroma quoianum*		X	X		
Australian spotted jellyfish *Phyllorhiza punctata*	X				X
Australian tubeworm *Ficopomatus enigmaticus*		X			X
Baltic clam *Macoma petalum*		X			X
Bamboo worm *Sabaco elongatus*		X			X

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Black Sea jellyfish *Blackfordia virginica*		X		X	
Black Sea jellyfish *Maeotias marginata*		X			X
Blacktip shipworm *Lyrodus pedicellatus*		X			X
Blue mussel *Mytilus complex*	X				X
Bonnet limpit *Sabia conica*	X			X	
Brackish water snail *Assiminea parasitologica*		X		X	
Brown bryozoan *Bugula neritina*		X		X	
Bryozoan *Bugula stolonifera*		X			X
Bryozoan *Cryptosula pallasiana*	X	X		X	
Bryozoan *Victorella pavida*		X			X
Bryozoan *Watersipora arcuata*		X			X
Bryozoan *Watersipora subtorquata*		X		X	
Bryozoan *Zoobotryon verticillatum*		X			X
Capitellid worm *Capitella telata*		X		X	
Channeled whelk *Busycotypus canaliculatus*		X			X
Chinese mitten crab *Eriocheir sinensis*		X			X
Ciliate *Mirofolliculina limnoriae*		X			X
Colonial tunicate *Didemnum vexillum*		X	X		

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Common Atlantic slippersnail *Crepidula fornicata*		X			X
Common sea grape *Molgula manhattensis*		X		X	
Convex slippersnail *Crepidula convexa*		X			X
Copepod *Amphiascus parvus*		X			X
Copepod *Corycaeus anglicus*		X		X	
Copepod *Coullana canadensis*		X		X	
Copepod *Limnoithona tetraspina*		X		X	
Copepod *Oithona davisae*		X		X	
Copepod *Oithona similis*		X		X	
Copepod *Pseudodiaptomus forbesi*		X			X
Copepod *Pseudodiaptomus marinus*		X			X
Copepod *Pseudomyicola spinosus*		X			X
Copepod *Stephos pacificus*		X			X
Copepod *Tortanus sp.*		X			X
Creeping bryozoan *Bowerbankia “gracilis”*	X	X		X	
Crumb-of-bread sponge *Halichondria bowerbanki*	X	X		X	
Crustacean *Deltamysis holmquistae*		X			X
Crustacean *Eochelidium sp.*		X			X

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Crustacean *Eusarsiella zostericola*		X			X
Crustacean *Hyperacanthomysis longirostris*		X			X
Crustacean *Sinelobus sp.*		X		X	
Delphaeid planthopper *Prokelsia marginata*		X			X
Eastern mudsnail *Ilyanassa obsoleta*		X			X
Eastern white slipper shell *Crepidula plana*		X			X
European green shore crab *Carcinus maenas*	X			X	
False anglewing *Petricolaria pholadiformis*		X			X
Flat okenia *Okenia plana*		X			X
Flatworm *Koinostylochus ostreophagus*		X			X
Foolish mussel *Mytilus (trossulus x galloprovincialis)*	X				X
Foram *Trochammina hadai*		X			X
Freshwater hydroid *Cordylophora caspia*		X		X	
Golden star tunicate *Botryllus schlosseri*		X		X	
Griffen's isopod *Orthione griffenis*	X	X	X		
Hard shell clam *Mercenaria mercenaria*		X			X
Harris mud crab *Rhithropanopeus harrisii*		X		X	

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Hydroid *Moerisia sp.*		X			X
Hydroid *Corymorpha sp.*		X			X
Isopod *Dynoides dentisinus*		X			X
Isopod *Eurylana arcuata*		X			X
Isopod *Iais californica*		X		X	
Isopod *Paranthura sp.*		X			X
Isopod *Pseudosphaeroma sp.*		X		X	
Isopod *Spharoma quoianum*		X	X	X	
Isopod *Synidotea laevidorsalis*		X			X
Japanese clam *Neotrapezium liratum*		X			X
Japanese false cerith *Batillaria attramentaria*		X			X
Japanese littleneck clam *Venerupis philippinarum*	X	X		X	
Japanese mussel *Musculista senhousia*		X			X
Japanese nassa *Hima fratercula*		X			X
Japanese oyster drill *Ocinebrellus inornatus*		X	X		
Japanese skeleton shrimp *Caprella mutica*		X		X	
Lacy crust bryozoan *Conopeum tenuissimum*		X		X	
Lagoon sea slug *Tenellia adspersa*		X		X	

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Lake Merritt cuthona *Cuthona perca*		X			X
Manchurian cecina *Cecina manchurica*		X			X
Marsh snail *Myosotella myosotis*		X		X	
Mediterranean blue mussel *Mytilus galloprovincialis*	X				X
Misaki balloon aeolis *Eubranchus misakiensis*		X			X
Moon jelly *Aurelia sp.*	X	X			X
Mysid *Orientomysis aspera*		X			X
Naval shipworm *Teredo navalis*		X		X	
New Zealand amphipod *Paracorophium sp.*		X			X
New Zealand mudsnail *Potamopyrgus antipodarum*		X	X		
New Zealand sea slug *Philine auriformis*	X	X		X	
Nodding head *Barentsia benedeni*		X		X	
Orange anemone *Diadumene cincta*		X			X
Orange-striped green anemone *Diadumene lineata*		X		X	
Oriental shrimp *Palaemon macrodactylus*		X		X	
Oyster redworm *Mytilicola orientalis*		X		X	
Pacific oyster *Crassostrea gigas*		X		X	

Non-Native Species	**Nearshore**[a]	**Estuarine**[b]	**1: OR Invasive**[c]	**2: OR Non-native**[d]	**3: WA or CA Invasive (not known in OR)**[e]
Pacific transparent sea squirt *Ciona savignyi*		X		X	
Pile worm *Neanthes succinea*		X		X	
Pink mouth hydroid *Ectopleura crocea*		X		X	
Polychaete worm *Boccardia claparedei*		X		X	
Polychaete worm *Boccardiella hamata*	X			X	
Polychaete worm *Boccardiella ligerica*		X			X
Polychaete worm *Dipolydora quadrilobata*		X		X	
Polychaete worm *Eumida sanguinea*		X			X
Polychaete worm *Eusyllis japonica*		X			X
Polychaete worm *Heteromastus filiformis*	X			X	
Polychaete worm *Hobsonia florida*		X		X	
Polychaete worm *Manayunkia aestuarina*		X		X	
Polychaete worm *Polydora cornuta*		X		X	
Polychaete worm *Polydora limicola*		X		X	
Polychaete worm *Polydora neocaeca*		X		X	
Polychaete worm *Proceraea okadai*		X		X	
Polychaete worm *Pseudopolydora bassarginensis*		X		X	

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Polychaete worm *Pseudopolydora kempi*		X		X	
Polychaete worm *Pseudopolydora paucibranchiata*		X		X	
Polychaete worm *Rhynchospio foliosa*		X		X	
Polychaete worm *Streblospio benedicti*		X		X	
Polychaete worm *Syllis cornuta*		X		X	
Polyp aeolis *Cumanotus sp.*		X		X	
Purple acorn barnacle *Amphibalanus amphtrite*		X			X
Purple varnish clam *Nuttallia obscurata*	X	X	X		
Red beard sponge *Clathria prolifera*		X			X
Red-gilled Marphysa *Marphysa sanguinea*		X			X
Red-gilled mud worm *Marenzelleria viridis*		X			X
Ribbed mussel *Geukensia demissa*		X			X
Root-arm medusa *Cladonema radiatum*		X			X
Rope grass hydroid *Garveia franciscana*		X		X	
Rough periwinkle *Littorina saxatilis*		X			X
San Francisco anemone *Diadumene franciscana*		X			X
Sea grape *Molgula citrina*		X		X	

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Sea squirt *Diplosoma listerianum*		X		X	
Sessile hydrozoan *Gonothyraea loveni*		X		X	
Single horn bryozoan *Schizoporella japonica*		X		X	
Skeleton shrimp *Caprella drepanochir*		X		X	
Starlet sea anemone *Nematostella vectensis*		X		X	
Steamer clam *Mya arenaria*		X		X	
Transparent sea squirt *Ciona intestinalis*		X			X
Tube amphipod *Jassa marmorata*	X			X	
Tubificid worm *Limnodriloides monothecus*		X			X
Tubificid worm *Tubificoides brownae*		X		X	
Tubificid worm *Tubificoides diazi*		X		X	
Tubificid worm *Tubificoides wasselli*	X				X
Tunicate *Ascidia zara*		X			X
Tunicate *Botrylloides perspicuum*		X			X
Tunicate *Botryllus schlosseri*		X		X	
Tunicate *Ciona savignyi*	X				X
Tunicate *Didemnum vexillum*		X	X		
Tunicate *Diplosoma listerianum*	X	X		X	

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Tunicate *Perophora japonica*		X			X
Tunicate *Styela clava*		X		X	
Two-groove odostome *Odetta bisuturalis*		X			X
Violet tunicate *Botrylloides violaceus*		X		X	
White anemone *Diadumene leucolena*		X		X	
White-tentacled japanese aeolis *Sakuraeolis enosimensis*		X			X
Wood boring gribble *Limnoria quadripunctata*	X	X			X
Wood boring gribble *Limnoria tripunctata*	X	X		X	
Plants and Algae					
American sea rocket *Cakile edentula*		X		X	
Awosa *Ulva pertusa*		X		X	
Brass buttons *Cotula coronopifolia*		X		X	
Caulerpa seaweed *Caulerpa taxifolia*		X		X	
Coast barbgrass *Parapholis incurva*		X		X	
Common cordgrass *Spartina anglica*		X			X
Dead man's fingers *Codium fragile subsp. fragile*		X			X
Dense-flowered cordgrass *Spartina densiflora*		X		X	

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
English cordgrass *Spartina anglica*		X		X	
Eurasian water-milfoil *Myriophyllum spicatum*		X		X	
European sand spurry *Spergularia salina*		X		X	
European sea rocket *Cakile maritime*		X		X	
Japanese eelgrass *Zostera japonica*		X	X		
Japanese kelp *Undaria pinnatifida*	X				X
Japanese seaweed *Sargassum muticum*	X		X		
Marsh fleabane *Pluchea odorata odorata*		X			X
Red algae *Caulacanthus ustulatus*	X				X
Red algae *Ceramium kondoi*		X		X	
Red algae *Lomentaria hakodatensis*	X				X
Red algae *Polysiphonia brodiei*		X		X	
Redtop *Agrostis stolonifera*		X		X	
Salt meadow cordgrass *Spartina patens*		X		X	
Saltmarsh rush *Juncus gerardi*		X		X	
Sargassum *Sargassum muticum*	X				X
Smooth cordgrass *Spartina alterniflora*		X		X	
Spiny naiad *Najas marina*		X			X

Non-Native Species	Nearshore [a]	Estuarine [b]	1: OR Invasive [c]	2: OR Non-native [d]	3: WA or CA Invasive (not known in OR) [e]
Surf diatom *Attheya armatum*	**X**			**X**	

[a] Nearshore = species is primarily associated with the nearshore marine habitat, between the high tide line and the territorial sea boundary.

[b] Estuarine = species is primarily associated with estuarine habitat.

[c] 1: OR Invasive = non-native species is present in Oregon and is considered invasive for posing a threat to native species.

[d] 2: OR Non-native = non-native species is present in Oregon and the threat to native species is unknown

[e] 3: WA or CA Invasive = species is present in states adjacent to Oregon and is considered invasive.

Species listed here are associated with nearshore and estuarine west coast habitats, as determined by analysis of data and expert review provided by James T. Carlton, Williams College; John Chapman, Oregon State University; Debbie Reusser, U.S. Geological Survey – Western Fisheries Research Center; Henry Lee, U.S. Environmental Protection Agency – Western Ecology Division; and Gayle Hansen, Oregon State University.