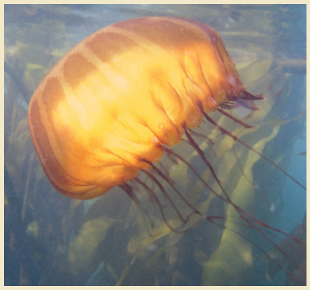
# APPENDIX – NEARSHORE CLIMATE FACT SHEETS

Oregon’s State Wildlife Action Plan



# SWAP

## 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. 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. 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. 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. 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. 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. 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. 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.

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. During upwelling conditions, zooplankton populations are higher but species diversity tends to be lower than during winter downwelling conditions. Along with upwelled water, plankton is carried from the highly productive continental shelf and broadly distributed by the California Current System.

When the delivery of nutrient-rich bottom water is delayed, primary production of marine algae and phytoplankton are also postponed. Transport of planktonic fish and invertebrate larvae in circulating waters may not occur in time for successful replenishment of coastal populations. 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. Marine species will likely need to make adjustments to regular timing of life activities and may respond by moving north or towards shore. Many nearshore marine fish, including rockfishes, salmon, and sardine, require strong upwelling for high offspring survival.

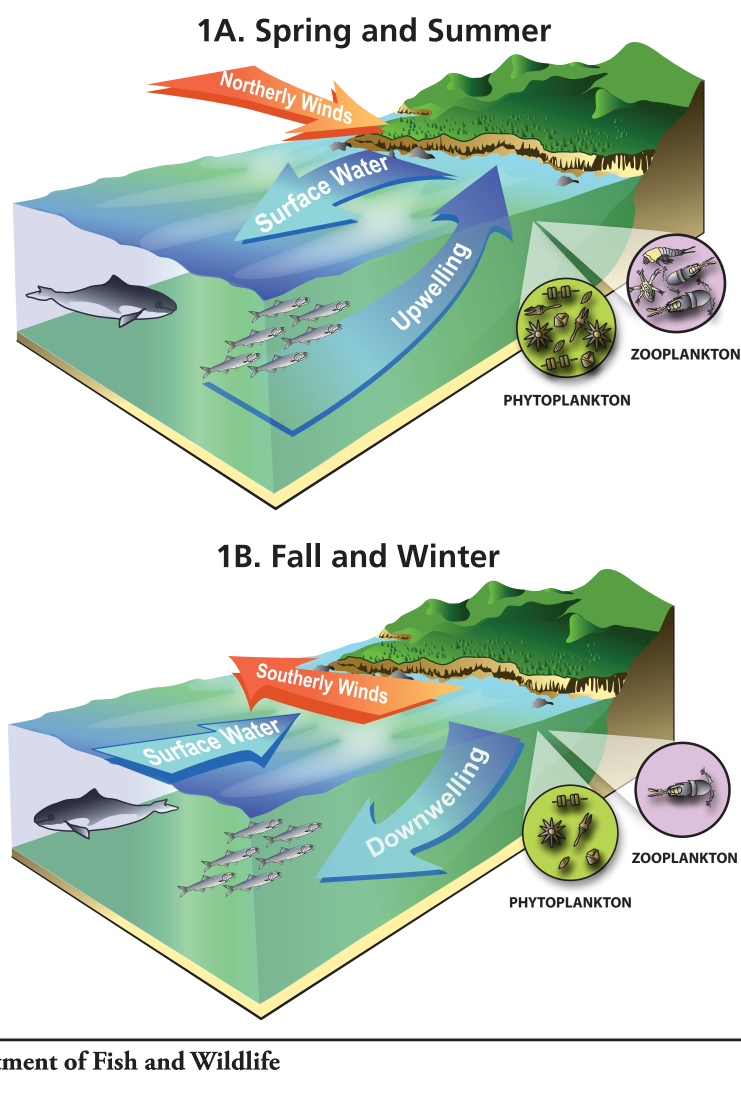



***Figure 1. Upwelling and Downwelling***

**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. 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. El Niño events have intensified in recent decades and may become more intense and more frequent in coming years.

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

### *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 as most of the heat added to the atmosphere is absorbed by the ocean. 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. Warming conditions can affect open water community in many ways including decreased plankton productivity, changes in species abundance, and shifts in species distribution northward.

As ocean temperatures warm, distributions of fish and other mobile animals are moving northward, likely associated with species-specific temperature requirements. Northward population shifts may also be linked to temperature-associated food source availability. Around the globe, distributions of many tuna, shark, and marine mammal species may shift significantly as a result of warming sea temperatures. Fish and marine mammal biodiversity may actually increase off the Oregon coast, with an influx of warm-water species from the south. 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. The abundance, distribution, and spawning success of Pacific sardine are strongly influenced by sea surface temperature. Jellyfish abundance can change dramatically from year to year based on fluctuations in sea surface temperature. Jellyfish can quickly replace fish as dominant species if populations are subjected to major environmental change.

**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. For example, hake and Pacific sardine have recently spawned in waters off Oregon and Washington. 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. 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. 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. 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, and the area where the plume meets the ocean generates productive conditions that attract many species of fish, seabirds, and marine mammals. Planktonic communities concentrate along this boundary and provide a unique and valuable resource for upper trophic level consumers, like salmon and other fishes.

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. 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. 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.

### *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. In addition, anoxia was initially documented in 2006. Dissolved oxygen concentrations have been declining in Oregon's coastal waters since the 1960s.

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

Marine organisms require dissolved oxygen to live and when dissolved oxygen levels decrease, marine species may suffer stunted growth, abnormal behavior, or death. 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. 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. In 2002, a particularly strong hypoxic event led to fish kills in the nearshore.

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. In hypoxic conditions, the animals that eat jellyfish move elsewhere and moon jellyfish populations increase dramatically. Fish larvae become sluggish and are less able to escape being eaten by moon jellyfish, causing community composition to become out of balance. 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. The spread of hypoxia resulting from intensified upwelling may alter nearshore community relationships and ecosystem resilience may be reduced.

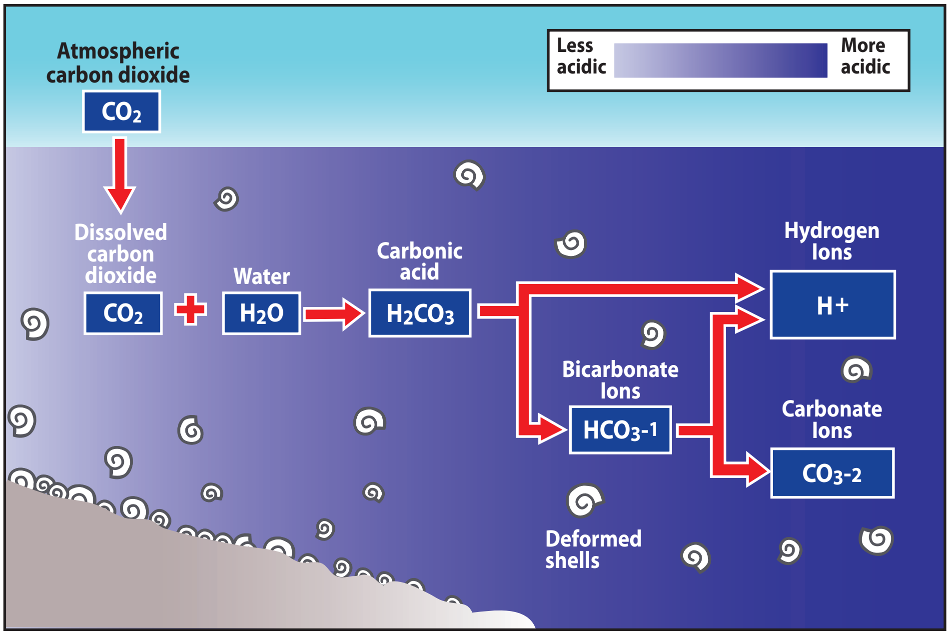



**Figure 2. *Ocean Acidification***
**The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms. As more carbon dioxide is absorbed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

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. 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. These effects could lead to higher mortality of significant food sources for upper trophic levels and larval fishes. These declines alter competition and predation dynamics and may contribute to increased populations of non-calcifying organisms. 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. 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.

**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. Management of marine resources should be flexible in order to adapt to climate change impacts and maintain resource sustainability in the future. 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.

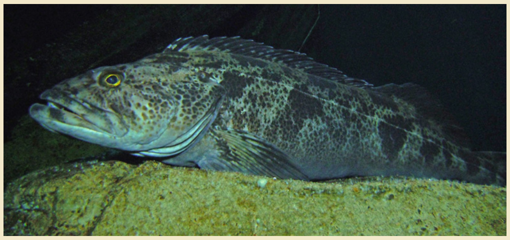
Species responses to short-term changes in environmental conditions need to be documented in order to predict how local populations are likely to respond when exposed to large-scale or long-term climate change impacts. Understanding of these variables will continue over time by building the region's 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*

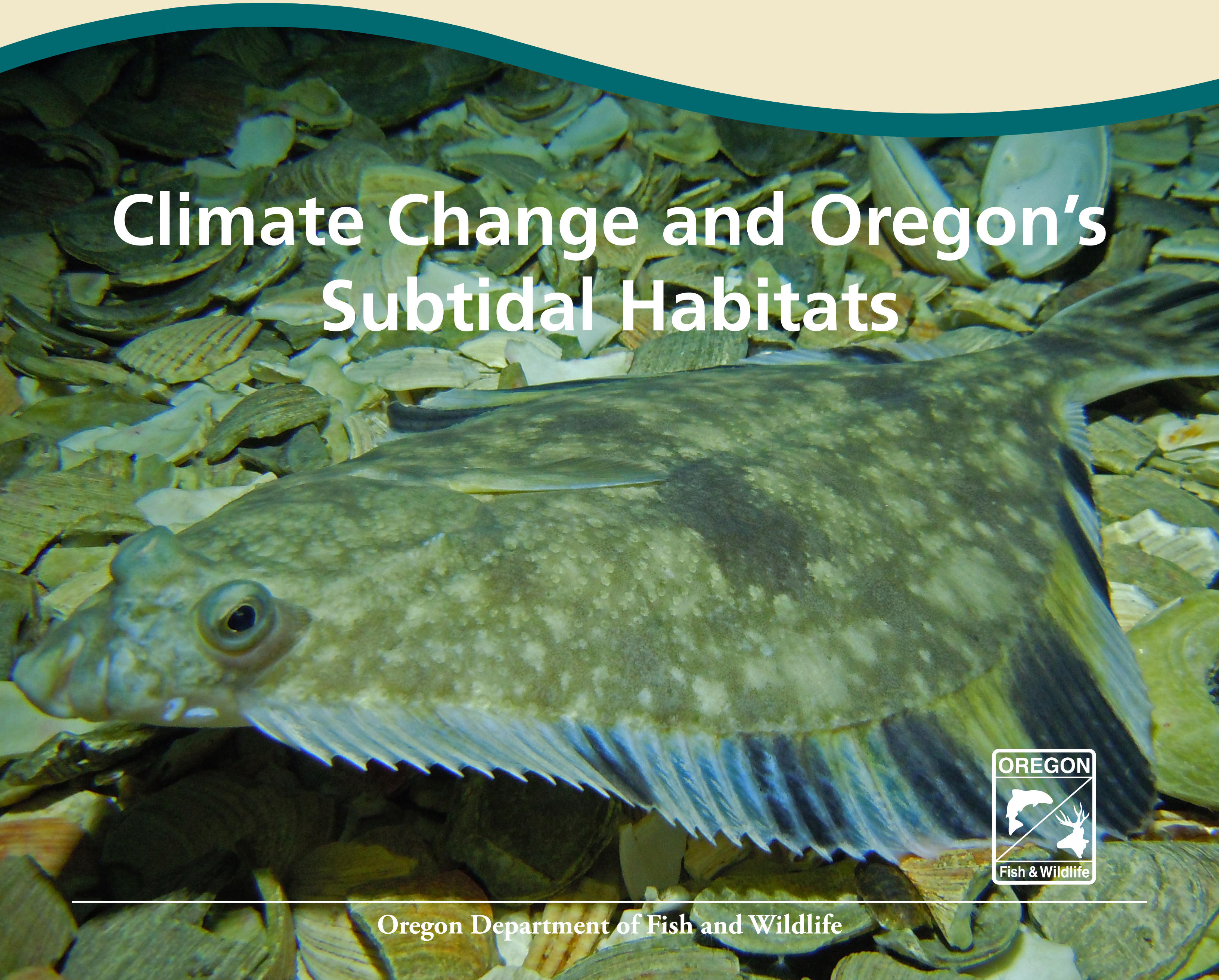
Photosynthesis by phytoplankton, microscopic plant-like organisms, is a critical link in nutrient cycling in the ocean. As the base of the marine food web, phytoplankton will respond first to climate change impacts. Globally, primary productivity from oceanic phytoplankton has decreased over the last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

Off the Oregon coast, primary productivity levels change from year to year and are affected by the annual upwelling cycle and interannual ENSO events. With climate change, the onset of spring upwelling may be delayed, 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. El Niño events may become more intense and more frequent, 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. 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. 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.

# SWAP



## FACT SHEET



# 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. 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. 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. 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.

The variety of topography, substrate characteristics, and depths within and among subtidal habitats produce a densely packed and highly diverse set of microhabitats, 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. 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. 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. 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. 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. Populations that are relatively isolated on patchy habitat are reliant on larval dispersal for replenishment, a process that may be altered by environmental change. These changes could potentially lead to insufficient replenishment to maintain populations and reduced genetic variability, as well as altered community structure.

### *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.

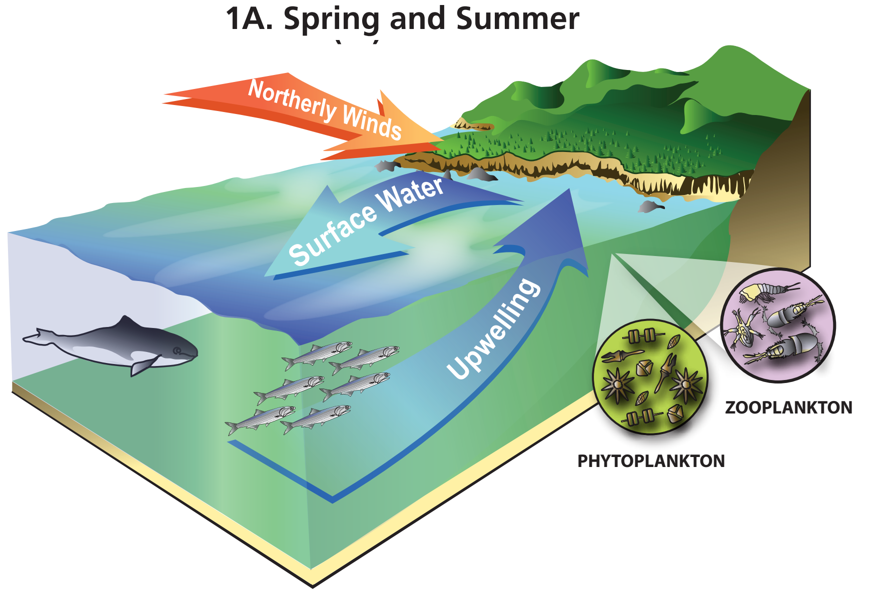
Climate change may alter the patterns of seasonal upwelling and downwelling that make up the annual cycle (Figure 1). Upwelling is the wind-driven circulation of cold, nutrient-rich water from deep in the ocean up to nearshore waters in the spring and summer. Downwelling is the movement of warmer, oxygen-rich 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.

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. 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. 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.

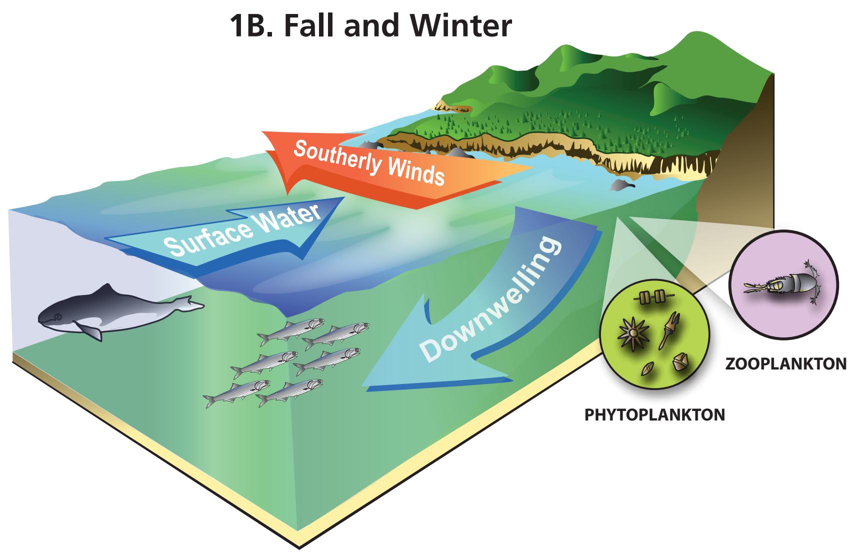
As an example, Dungeness crab larvae generally hatch mid-winter and spend three months developing in open waters far from shore before returning to the coastline in upwelled waters in early March. If upwelling is delayed, megalopae (baby crabs) spend more time in open waters where they are eaten by other 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.

***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. 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. El Niño events have intensified in recent decades and may become more intense and more frequent in coming years.

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

Populations of young rockfishes have low abundances during El Niño conditions. 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.

### *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. In addition, anoxia was initially documented in 2006. Dissolved oxygen concentrations have been declining in Oregon's coastal waters since the 1960s.

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. Since 2000, hypoxia has been observed within approximately 80 percent of the nearshore water column between June and October. Areas affected by hypoxia increase in size during summer upwelling. Respiration can depress low oxygen levels in the upwelled water even further especially in highly productive areas.

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. 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. 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. Seasonally-persistent anoxia or hypoxia greatly impacts organisms that live on the ocean floor or in bottom waters. Hypoxic areas have greater displacement of mobile species that are driven out of preferred habitats. 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.

Displacement of mobile species will put additional pressure on adjacent habitats, where increased predation could alter a broad range of marine populations. 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. If prey animals are tolerant to hypoxic conditions, then populations would be expected to increase and habitat quality may be indirectly affected. 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 as most of the added heat to the atmosphere is absorbed by the ocean. 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. 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.

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 making ocean mixing less effective at bringing nutrients to the surface, thereby reducing primary productivity. Reduced productivity means less food is available at the base of marine food webs, 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. Northward population shifts may also be linked to temperature-associated food source availability. 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. While some species may react poorly to changing temperature conditions, others, including arthropods and annelids, may be less vulnerable. Predominant species abundance may shift from one group to another. Overall, biological communities on and in seafloor habitats are predicted to respond to warming conditions with altered community structure and shifts in species diversity.

### *Ocean Acidification*

The world's oceans are becoming increasingly acidic as more atmospheric carbon dioxide is absorbed into the ocean. 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.

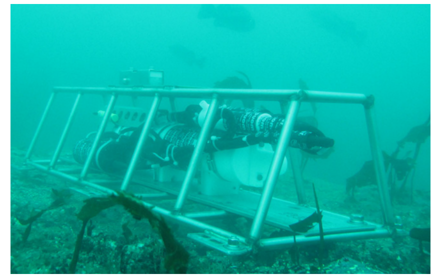
Seawater contains carbonate ions that are necessary for skeleton and shell formation. However, when carbon dioxide reacts with seawater, the availability of carbonate is reduced and successful development of shellfish, corals, and planktonic food sources that support fisheries, including salmon and groundfish,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

Shell-forming organisms may suffer reduced individual size and decreased populations as seawater becomes more acidic. 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. 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, 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. 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. 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.

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. Management of marine resources should be

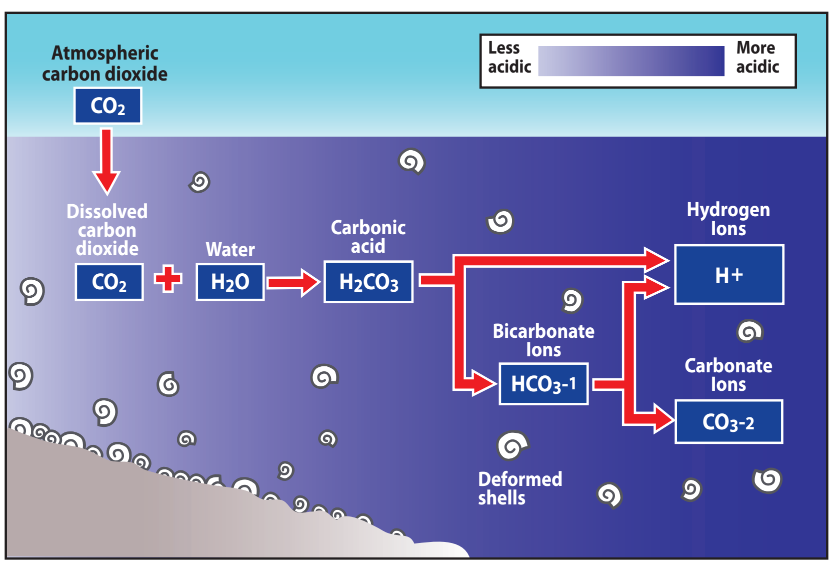



***Figure 2. Ocean acidification.*** **The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms. As more carbon dioxide is absorbed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

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. 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.

# SWAP

## FACT SHEET

# 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. 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. 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. 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.

**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. Delayed or low levels of primary productivity may not support many intertidal organisms for which food availability is time-sensitive. 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. Key invertebrate predators including sea stars and whelks are most densely populated during the upwelling season. 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. 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.

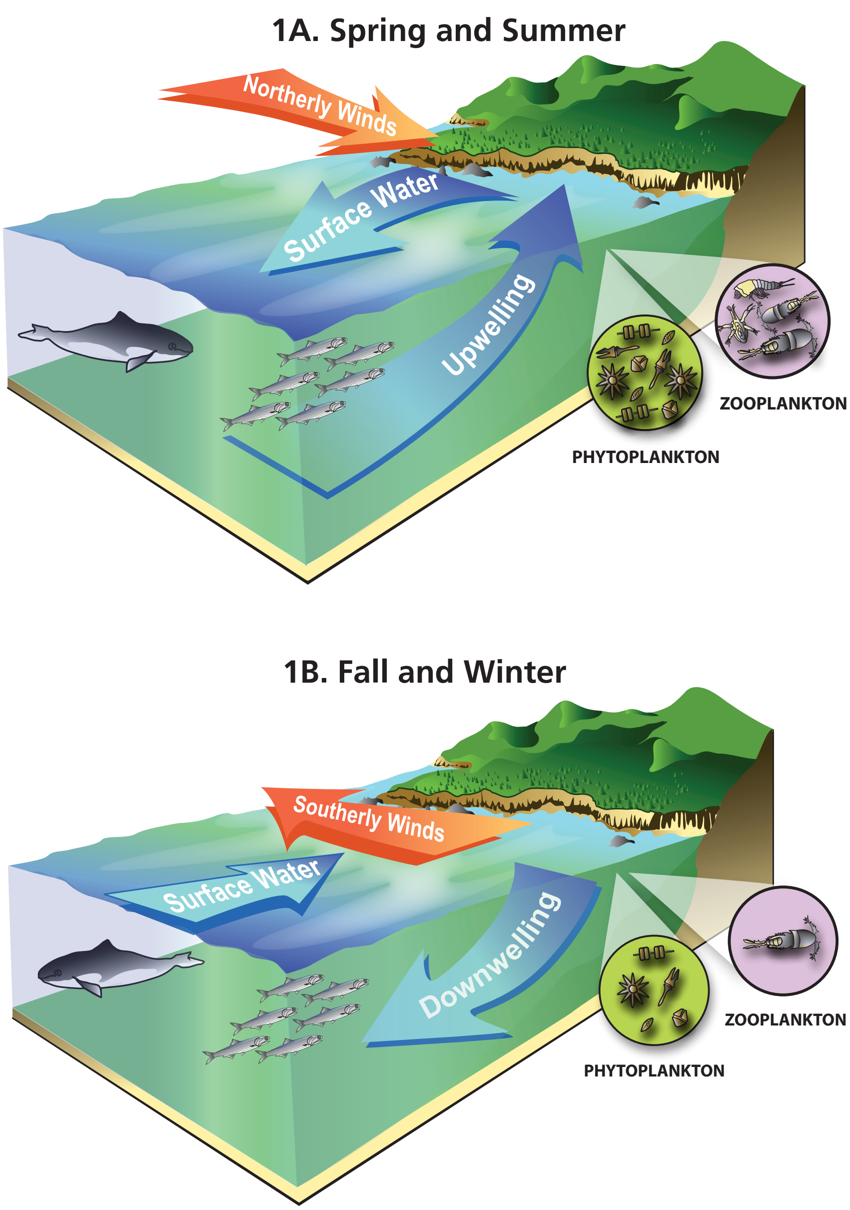



***Figure 1. Upwelling and Downwelling***

**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 as most of the added heat to the atmosphere is absorbed by the ocean. 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. Warming conditions affect intertidal community dynamics in many ways including shifts in species distribution towards the poles and altered growth of marine organisms.

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. These species distribution shifts may be linked to the availability of food sources that require specific temperatures. 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.

Some species, such as mussels, will grow larger or faster due to an accelerated metabolic response to warmer water temperatures. 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.

### *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. 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. 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. Beach sediment distribution will be altered, leading to habitat changes such as beach slope and grain size.

Sea level rise may correspond to modified reproductive timing or success for marine beach-spawning populations. 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. Without certain conditions (e.g., temperature, humidity, elevation, light exposure) survival of young will be substantially reduced.

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. Rising sea levels will reduce the availability and suitability of beach haulout sites for harbor seals. Decreased densities of intertidal crabs are associated with sea level rise. The upper range of the California mussel continues to expand upwards as sea levels rise, competing with other attached invertebrates for space. The range of a key predator, the ochre sea star, is also expanding, increasing predation rates on attached intertidal invertebrates. 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.

**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. As a result, greater erosion of shoreline habitats has been caused by increased wave action and more turbulent waters washing the beach. 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. 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. As storms intensify, so does the amount of wave energy approaching the shore from different directions, which can accelerate erosion of sandy beach habitats.

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. 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.

## *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. 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 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. 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.

Shell-forming organisms may suffer reduced individual size and decreased populations as seawater becomes more acidic. 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. Tidepool conditions change naturally between high and low levels of oxygen and carbon dioxide as animals breathe and incoming tides flush the pools. However, as acidic waters increasingly impact intertidal habitats, resident organisms may need to adapt by making costly trade-offs to stay alive. 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. 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.

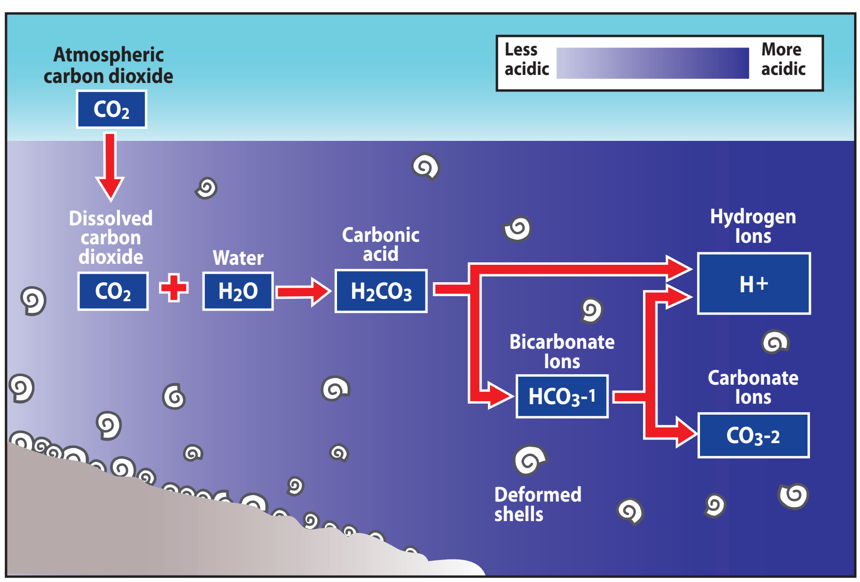
Species interactions and predation dynamics are expected to change under acidic conditions, leading to reduced species diversity and changes in community structure. The effects of water temperature and acidity can interact to produce complex species responses that impact community abundance and diversity. 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. Acidification can alter competition among species and predation behaviors, contributing to increased populations of algae and organisms that don't develop shells. 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. 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.  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. Management of marine resources should be flexible in order to adapt to climate change impacts and maintain resource sustainability in the future. 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.

Oregon's intertidal habitats are occupied by specialized organisms that are well adapted to high-energy and highly changeable environments. 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. Understand-ing 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, 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. As upwelling patterns are disrupted, the timing and strength of transport of cold, nutrient-rich oceanic waters to the nearshore may be altered. This infusion of water is responsible for highly productive algal blooms that occur in the nearshore during the summer. 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. At the same time, changes in freshwater input may increase nutrient input, further contributing to toxic algal blooms.

Phytoplankton and algae form the base of intertidal marine food webs and produce the food and energy required to sustain life in nearshore waters. Some species produce domoic acid, a toxin that accumulates in intertidal shellfish and can induce amnesic shellfish poisoning in humans. Other species can produce the toxin responsible for paralytic shellfish poisoning in humans. 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. Increasing harmful algal blooms may translate to ecosystem, economic, and/or human health concerns.