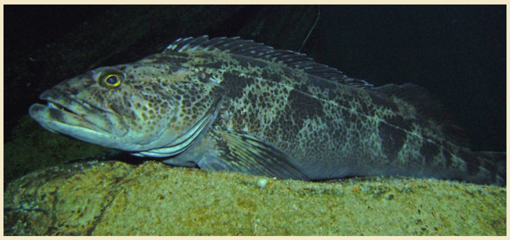
the OREGON CONSERVATION STRATEGY



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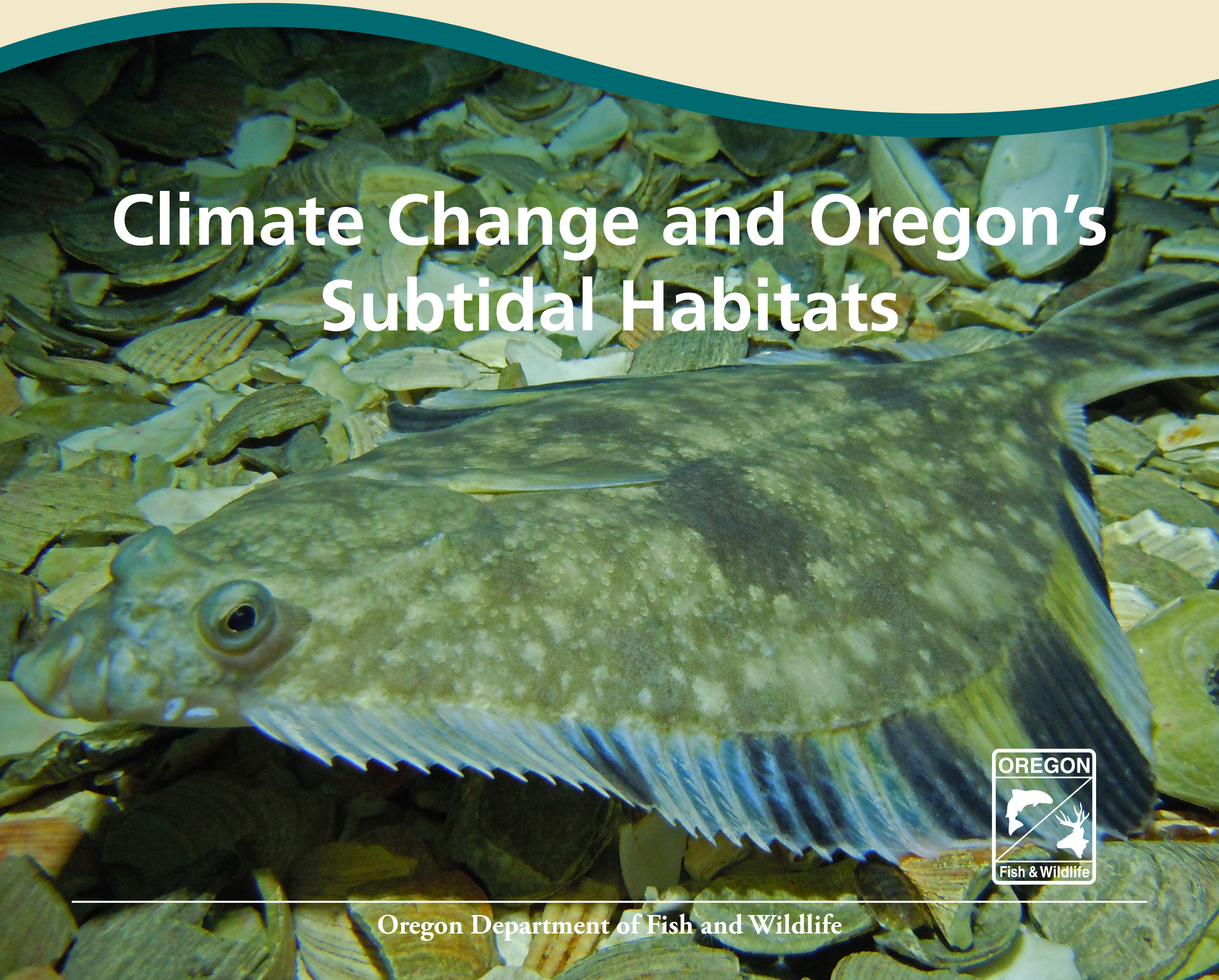


Climate Change and Oregon's Subtidal Habitats

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.

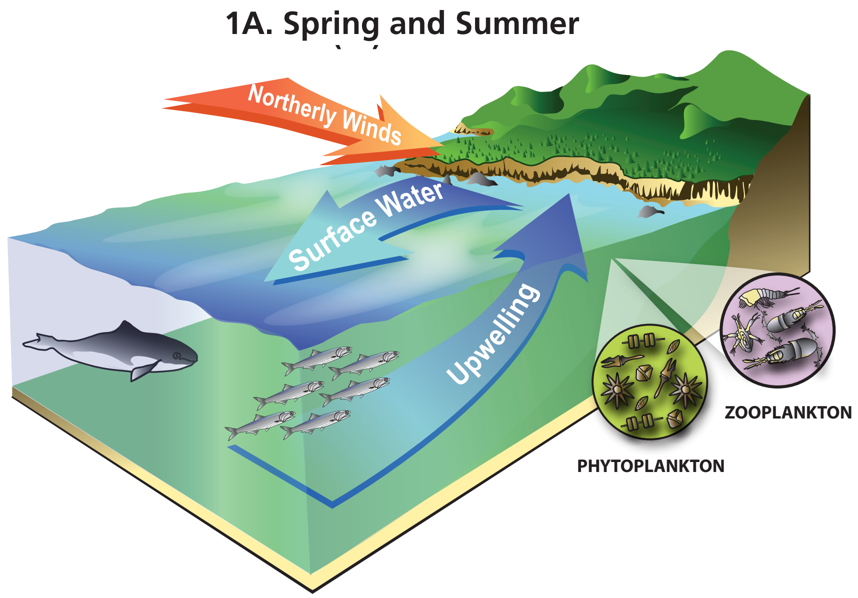
Climate change may alter the patterns of seasonal upwelling and downwelling that make up the annual cycle (Figure 1). Upwelling is the wind-driven circulation of cold, nutrient-rich water from deep in the ocean up to nearshore waters in the spring and summer. Downwelling is the movement of warmer, oxygen-rich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

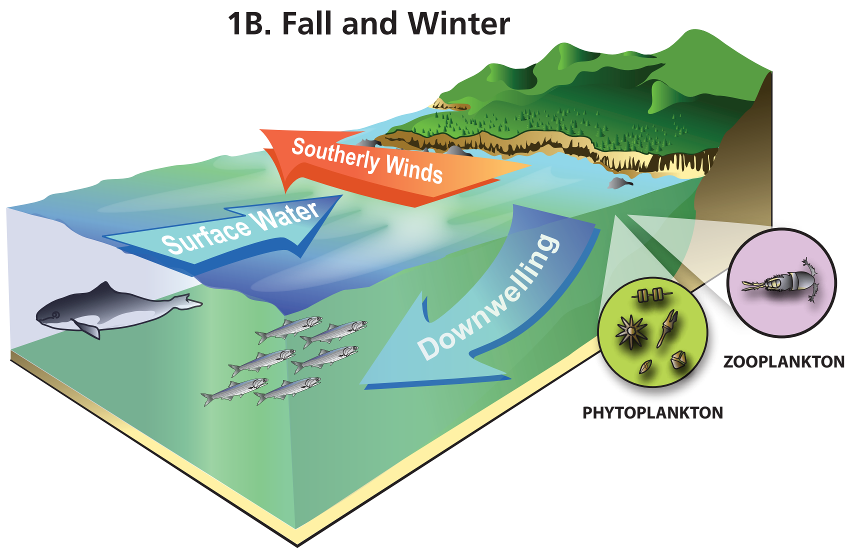
As an example, Dungeness crab larvae generally hatch mid-winter and spend three months developing in open waters far from shore before returning to the coastline in upwelled waters in early March[9]. If upwelling is delayed, megalopae (baby crabs) spend more time in open waters where they are eaten by 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).

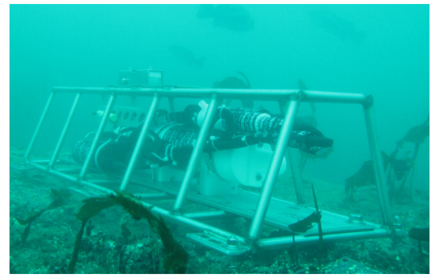
Shell-forming organisms may suffer reduced individual size and decreased populations as seawater becomes more acidic[18]. Organisms living on or beneath soft bottom sediments are also vulnerable to impacts of acidification. Acidification has resulted in decreased fertilization rates in sea urchins, and 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.

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.

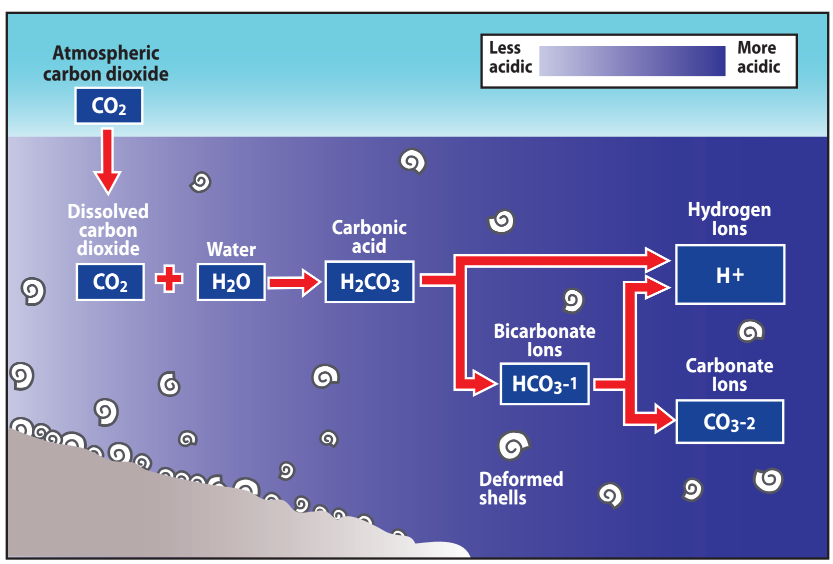


Underwater oceanographic data collection. ODFW photo.

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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