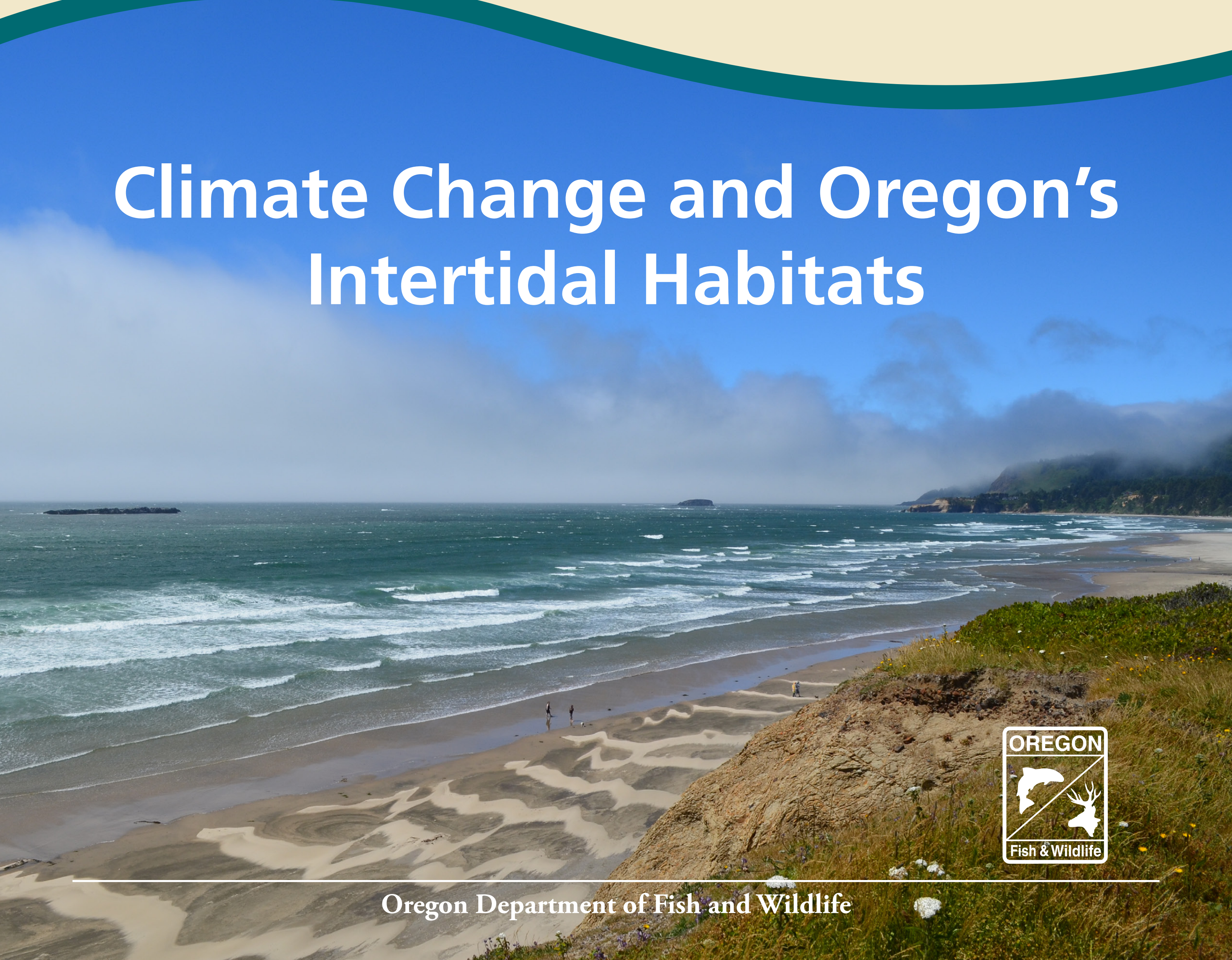
the OREGON CONSERVATION STRATEGY

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[1]. The physical environment changes dramatically as the tide rises and falls, subjecting organisms to constant variations of exposure to air, waves, freshwater and sun. Local currents and ocean circulation introduce additional variables to the habitat, including sand scour of rocks, seasonal burial of rocky areas, and transport of food, larvae, and nutrients to and from intertidal sites. Seasonal variation in wind, wave energy and currents move substantial amounts of sand onto or away from the intertidal zone, resulting in significant changes in habitat characteristics throughout the year.

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

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

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

Consequences of Increased Carbon Dioxide for Oregon's Intertidal Areas

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

Changes in Oceanic Cycles

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

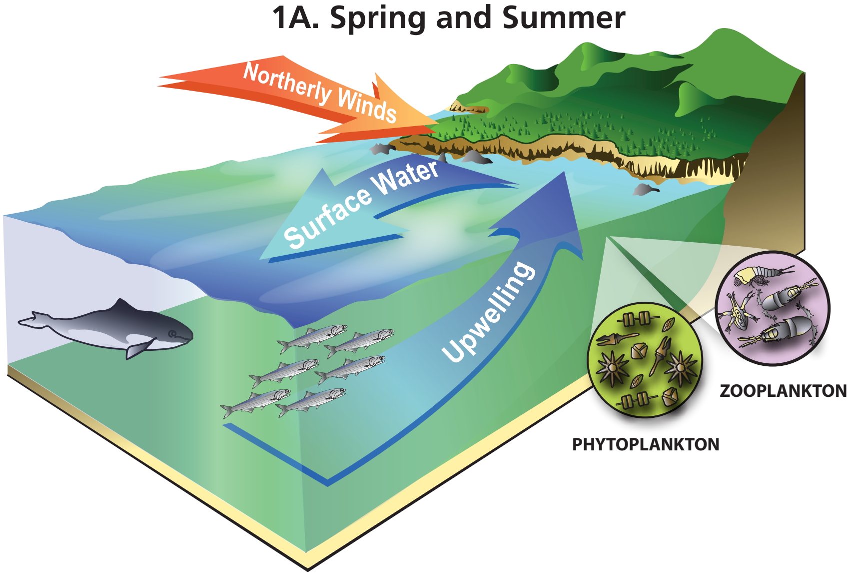
Climate change may alter the patterns of seasonal upwelling and downwelling that make up the annual cycle (Figure 1). Upwelling is the wind-driven circulation of cold, nutrient-rich water from deep in the ocean up to nearshore waters in the spring and summer. Downwelling is the movement of warmer, oxygen-rich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

Cover Photos: ODFW

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

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

1A. Spring and Summer



1B. Fall and Winter

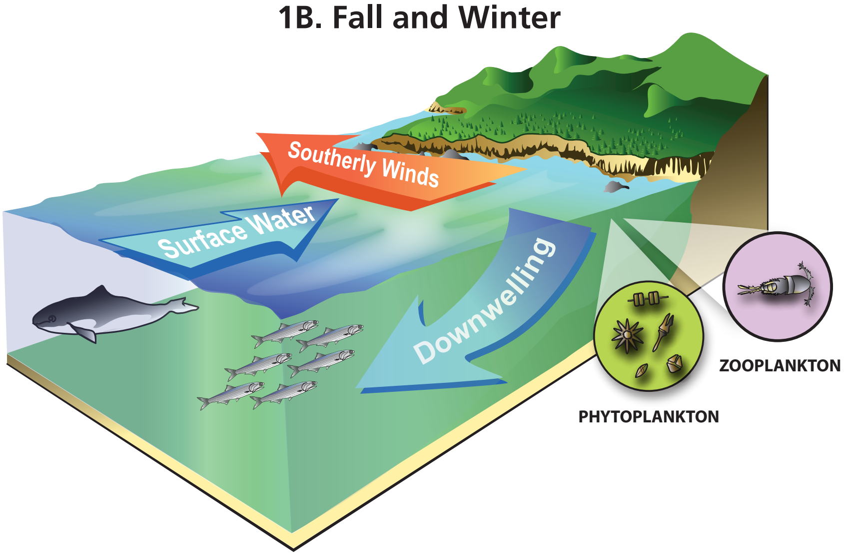


Figure 1. Upwelling and Downwelling

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

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

Warming Ocean Temperatures

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

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

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

Sea Level Rise

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

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

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

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

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

Harbor seals using sandy beaches. ODFW photo.

Ochre sea stars consuming California mussels. David Cowles photo.

Coastal Storms and Wave Height

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

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

Changes in Freshwater Input

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

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

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

Ocean Acidification

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

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

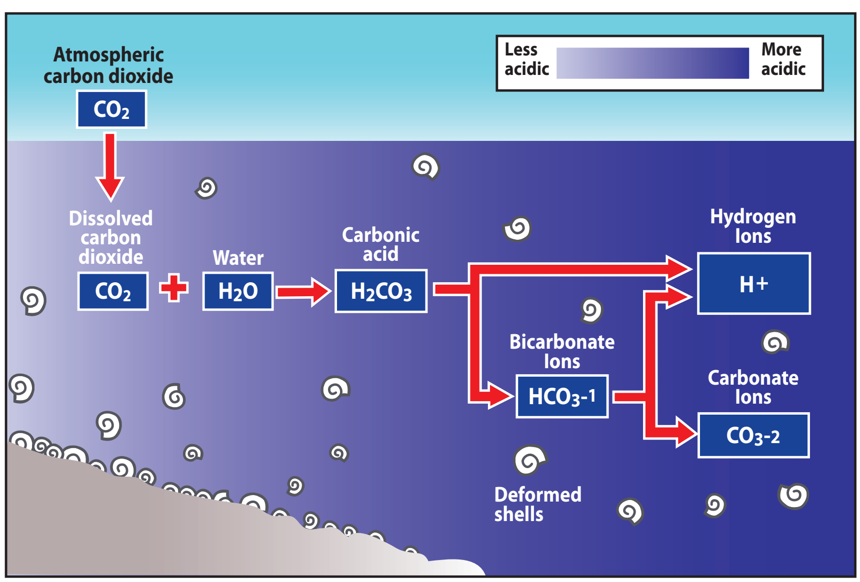
Species interactions and predation dynamics are expected to change under acidic conditions, leading to reduced species diversity and changes in community structure[29,31]. The effects of water temperature and acidity can interact to produce complex species responses that impact community abundance and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

Managing for Climate-adaptive Intertidal Areas

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

Figure 2. Ocean acidification

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



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

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

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

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

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

Harmful Algal Blooms and Climate Change

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

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

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

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