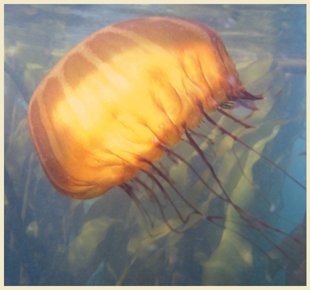


the OREGON CONSERVATION STRATEGY

FACT SHEET

Climate Change and Oregon's Nearshore Open Water Habitat

Oregon Department of Fish and Wildlife

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

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

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

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

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

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

Changes in Oceanic Cycles

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

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

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

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

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

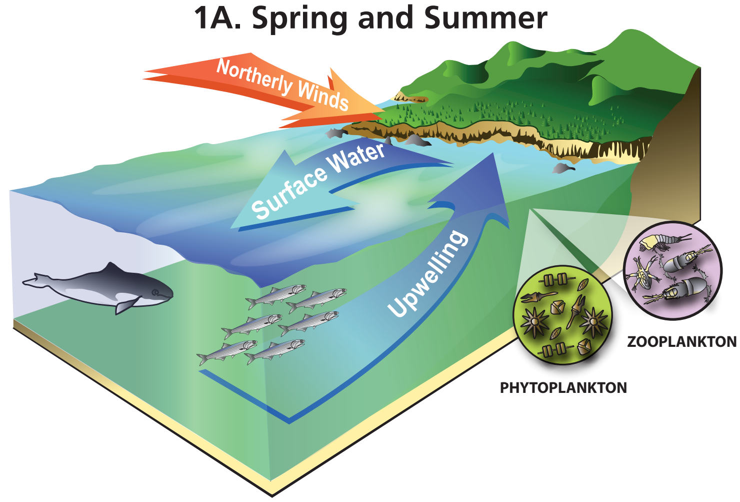
When the delivery of nutrient-rich bottom water is delayed, primary production of marine algae and phytoplankton are also postponed[5]. Transport of planktonic fish and invertebrate larvae in circulating waters may not occur in time for successful replenishment of coastal populations[5]. Many migratory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

Figure 1. Upwelling and Downwelling

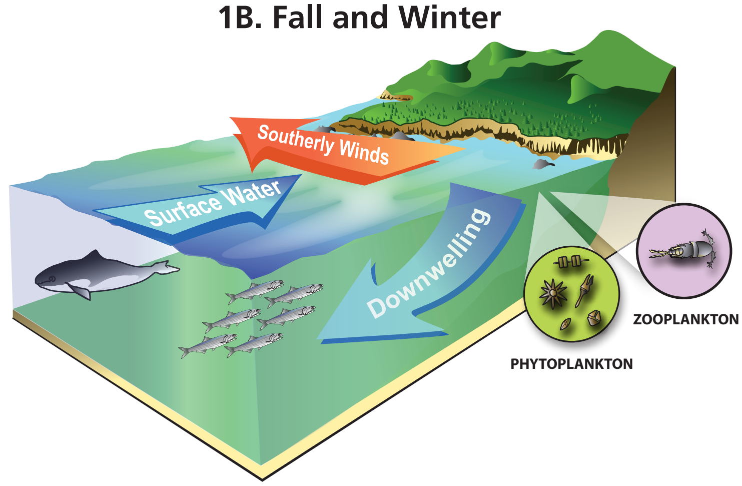
1A. During spring and summer, winds from the north blow parallel to the shore, exerting drag on the ocean's surface. The combination of energy transfer downward in the water column and the earth's rotation move surface waters off shore, 90 degrees to the right of the wind direction. This water is replaced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

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

1A. Spring and Summer



1B. Fall and Winter



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

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

Warming Ocean Temperatures

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

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

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

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

Changes in Freshwater Input

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

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

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

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

Changes in Hypoxia

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

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

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

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

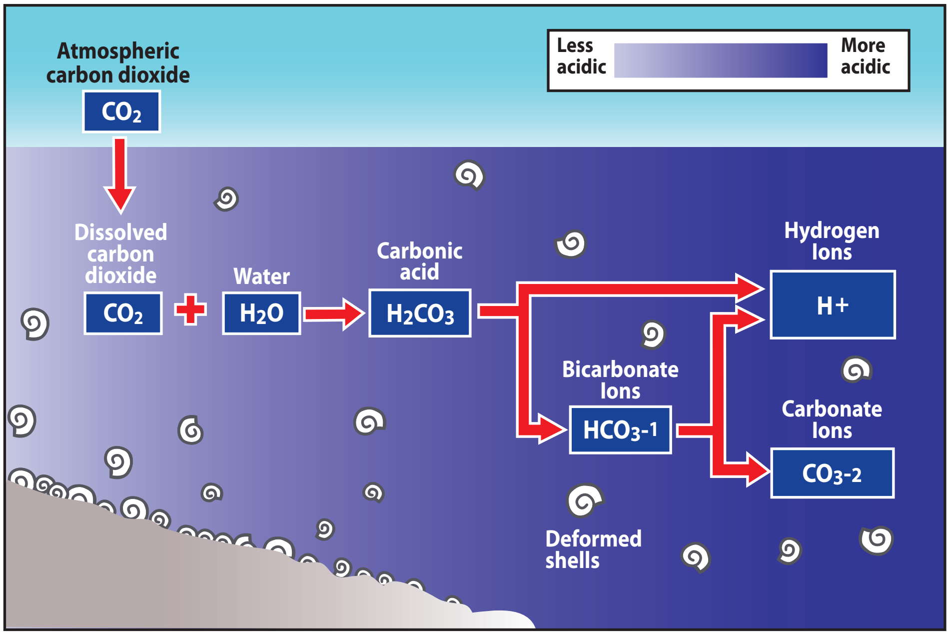


Figure 2. *Ocean acidification* **The absorption of carbon dioxide from the atmosphere reduces the availability of carbonate ions through a chemical reaction with seawater. These ions are necessary for the formation of skeletons and shells in many marine organisms. As more carbon dioxide is absorbed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

Ocean Acidification

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

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

Managing for Climate-adaptive Open Water Habitats

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

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

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

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

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

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

Primary Productivity and Climate Change

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

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

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