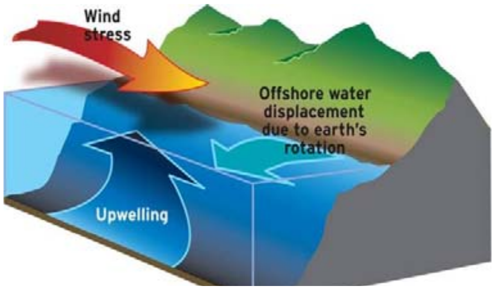
Earth Gauge
A National Environmental Education Foundation Program

Ocean Ecosystems and Climate Change

Ecosystems are never static and can undergo significant changes due to internal dynamics alone. One external factor with significant repercussions for local ecosystems is global climate change. Global climate change is affecting many interconnected variables important to marine ecosystems, including:

Temperature: Marine organisms are adapted to live in specific temperature ranges, as temperature has direct effects on physiological processes such as organ function. Water temperatures in the upper 2,300 feet of the oceans, where the vast majority of marine life lives, have increased on average about one degree Fahrenheit over the past century; this period has featured more range shifts towards the poles than towards the Equator.

Upwellings and Winds: Large-scale changes in Earth's climate system manifest in local changes in the timing and intensity of ocean current patterns. This is particularly true for *upwellings*, which are closely linked to surface winds that "pull" waters from the depths to the surface. Upwellings bring nutrients to the surface waters, feeding phytoplankton that in turn feed the rest of the life in the ocean; changes in the intensity and timing of upwellings impact the success of phytoplankton. Additionally, zooplankton – which consist largely of juvenile stages of invertebrate organisms, such as crabs, bivalves, sea stars and anemones − depend on ocean currents for dispersal.



Above: A diagram of the coastal upwelling that occurs on America's West Coast. Image NOAA.

Salinity: Changes in evaporation rates as Earth warms, as well as changes in freshwater input from land as precipitation patterns change and glaciers melt, can change the salinity of ocean waters. Some organisms are particularly sensitive to salinity changes: freshwater incursions into intertidal zones following rainstorms in the Pacific Northwest restrict the foraging area of starfish, and low-salinity levels linked to monsoon rains raise mortality rates amongst limpets in Southeast Asia. On a broader scale, salinity changes have implications for ocean circulation patterns, which are powered by disparities in both temperature and salinity.

Oxygen: Marine organisms become stressed or die when oxygen levels reach a certain minimum level, with large, mobile animals being the most sensitive. When circulation patterns expose parcels of ocean water to the surface, these parcels gain oxygen. On the other hand, it is at the sun-exposed surface where marine life consumes the most oxygen. The interplay between these two factors leads to semi-permanent oxygen minimum zones most commonly occurring between the depths of 1,300 and 4,000 feet. The extent and severity of these zones is closely linked to climate variability. Oxygen is less soluble in warmer waters, and climate change means changes in ocean circulation patterns and biology. Off the Oregon Coast, for example, spring winds pull nutrient rich water from the ocean depths, causing phytoplankton blooms. These blooms are followed by periods of decay when most of the available oxygen from the ocean bottom is consumed, resulting in a seasonal *dead zone*. Particularly strong winds and upwelling in the 2000s resulted in strong blooms and expansions of this dead zone into the historically non-hypoxic inner shelf area. Over the last 50 years, trends in the North Pacific and the tropical oceans show a movement of the oxygen minimum zones towards the surface. This has often resulted in the mortality of marine animals that live in these regions of the ocean.

Atmospheric Carbon Dioxide: While higher levels of atmospheric carbon dioxide (CO_2) levels can stimulate plant growth on land, they do not have this same fertilizing effect on marine plants like kelp. Sea grasses, which evolved during the warm and carbon-rich Cretaceous period, are the exception and have higher growth rates with higher CO_2 levels. Atmospheric CO_2 levels have increased from 280 parts per million in the 1700s to almost 400 parts per million today, and these levels would be higher if not for ocean carbon uptake. As the oceans have absorbed CO_2, they have become about 26 percent more acidic. This means there is less available aragonite, which *calciferous organisms,* like coral and microscopic foraminiferans, use to construct their bodies. In the Southern Ocean around Antarctica, foraminiferans today have shells weighing about one-third less than they did in the 1700s. How marine organisms respond to changes in acidity levels is strongly influenced by concurrent temperature changes.

LEVELS OF RESPONSE

The impacts of the climate variables listed above can be understood at several levels:

- **Organismal Level:** An individual organism can respond to changes in a climatic variable, such as temperature, by acclimating, moving or dying. Other variables interact with temperature to determine the severity of the potential impact. In intertidal communities, for example, the impact of a rise in air temperature is moderated by factors such as water temperature, solar radiation, cloud cover, wave heights, tidal cycles, etc. Members of the same species of mussel experienced higher heat related mortality rates in United Kingdom tide pools than in Portuguese tide pools, despite the Portuguese locations having higher air and water temperatures. This may be due to low tide events at United Kingdom locations more frequently coinciding with midday temperature peaks.
- **Population Level:** Climate variables can affect life at a population level, such as through changes in ocean currents that alter transport processes and nutrient availability, which in turn affect species dispersal, location and overall population size. Population level responses to climate change vary spatially and temporally, with some populations within the same species possessing genetic traits that enable them to respond better to rapid changes than other populations.
- **Community Level:** Even relatively small changes in a climatic variable can have large effects at the community level. For example, in the North Sea there is a large phytoplankton bloom in the spring which happens when there are a certain number of daylight hours. Phytoplankton predators, called zooplankton, also hatch in the spring, but this emergence is determined more by temperature than daylight. A 1.6 degree Fahrenheit rise in water temperature in this region over the past 30 years has led to an advance in the average annual date of the zooplankton hatching, which now often happens earlier than the phytoplankton bloom. Because zooplankton feed fish, this small rise in temperature and mistiming between predator and prey has major implications for the entire ecosystem. This is one example of *trophic amplification*, the process by which small changes in one variable has nonlinear impacts like the one described above. Another example of trophic amplification is the introduction of new decapod species (10-legged arthropods like crabs or lobsters) into North Sea waters. These new species eat mussels; mussel beds, much like coral reefs, form a matrix on which hundreds of species depend for food and shelter. The loss of mussel beds has led to a reorganization of the North Sea ecosystem.

CASE STUDY: THE CALIFORNIA CURRENT SYSTEM

The California Current System (CCS) is a collection of surface currents and gyres that provide additional seasonal variability to the West Coast region. The surface waters in the northern California Current have warmed by a little over one-half a degree Fahrenheit in the last 50 years. Warmer surface water temperatures generally mean greater *stratification*, where warm, nutrient-poor waters sit on the surface and impede the flow of cool, nutrient-rich water from the depths. Periods over the last few decades when warmer waters predominate have been correlated with less biological productivity. On millennial time scales, however, the strength of the cool water upwellings has been strengthened during warmer periods in Earth's past. This may be due to the increase in the ocean-land temperature gradient that these periods featured, which can strengthen alongshore winds that favor upwelling.

The El Niño-Southern Oscillation (ENSO), the periodic shift in the eastern tropical Pacific between warm and cool phases, influences weather and ocean conditions around the world. During warm (El Niño) phases, waters are warmer off the California Coast, upwelling is weaker and there is less overall biological productivity on average. El Niño phases also mean more frequent winter storms and rainfall for the region, which influences freshwater discharge to the oceans, as well as land surface temperatures. Both freshwater inputs and the ocean-land temperature contrast affect winds, ocean currents and marine environments. Lastly, the upwelling of nutrient rich water in the CCS is exclusively seasonal in northern parts of the system (along the northern California and Oregon coasts) and largely seasonal in the southern parts. Significant interannual variation in the timing of the seasonal upwelling, which begins in the spring, exists. This upwelling is usually delayed during El Niño phases, which accounts for part of the general loss of biological productivity observed during these years.

Despite the overall loss of productivity during El Niño phases, these conditions do give animals better suited to warmer waters a competitive advantage. For example, El Niño phases mean more frequent visits from tropical game fish species such as Yellowfin Tuna and Dorado. Much uncertainty remains regarding how ENSO behaved during different climatic periods of Earth's past, such as periods several degrees warmer than the 20th century.

Above: A diagram of the eastern North Pacific current systems, showing areas dominated by different types of vertical water movements and masses. Image courtesy of NOAA.

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