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What are Phytoplankton?

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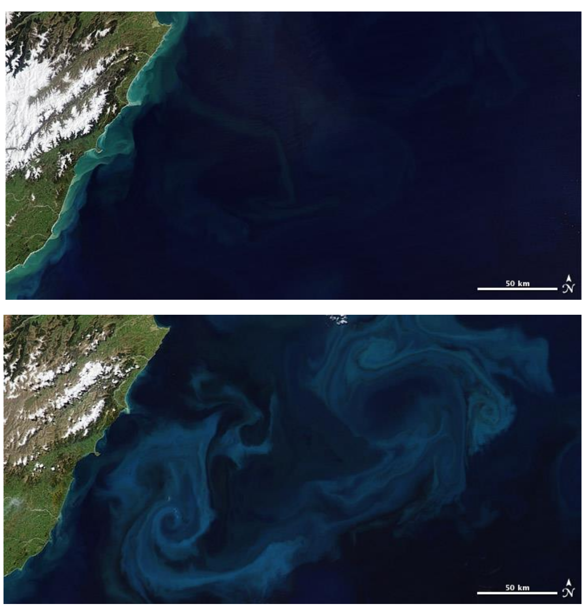
Derived from the Greek words *phyto* (plant) and *plankton* (made to wander or drift), phytoplankton are microscopic organisms that live in watery environments, both salty and fresh.

Some phytoplankton are bacteria, some are protists, and most are single-celled plants. Among the common kinds are cyanobacteria, silica-encased diatoms, dinoflagellates, green algae, and chalk-coated coccolithophores.

Phytoplankton are extremely diverse, varying from photosynthesizing bacteria (cyanobacteria), to plant-like diatoms, to armor-plated coccolithophores (drawings not to scale). (Collage adapted from drawings and micrographs by Sally Bensusen, NASA EOS Project Science Office.)

Like land plants, phytoplankton have chlorophyll to capture sunlight, and they use photosynthesis to turn it into chemical energy. They consume carbon dioxide, and release oxygen. All phytoplankton photosynthesize, but some get additional energy by consuming other organisms.

Phytoplankton growth depends on the availability of carbon dioxide, sunlight, and nutrients. Phytoplankton, like land plants, require nutrients such as nitrate, phosphate, silicate, and calcium at various levels depending on the species.



Phytoplankton can grow explosively over a few days or weeks. This pair of satellite images shows a bloom that formed east of New Zealand between October 11 and October 25, 2009. (NASA images by Robert Simmon and Jesse Allen, based on MODIS data.)

Some phytoplankton can fix nitrogen and can grow in areas where nitrate concentrations are low. They also require trace amounts of iron which limits phytoplankton growth in large areas of the ocean because iron concentrations are very low. Other factors influence phytoplankton growth rates, including water temperature and salinity, water depth, wind, and what kinds of predators are grazing on them.

When conditions are right, phytoplankton populations can grow explosively, a phenomenon known as a bloom.

Blooms in the ocean may cover hundreds of square kilometers and are easily visible in satellite images. A bloom may last several weeks, but the life span of any individual phytoplankton is rarely more than a few days.

IMPORTANCE OF PHYTOPLANKTON

The Food Web

Phytoplankton are the foundation of the aquatic food web, the *primary producers*, feeding everything from microscopic, animal-like zooplankton to multi-ton whales. Small fish and invertebrates also graze on the plant-like organisms, and then those smaller animals are eaten by bigger ones.

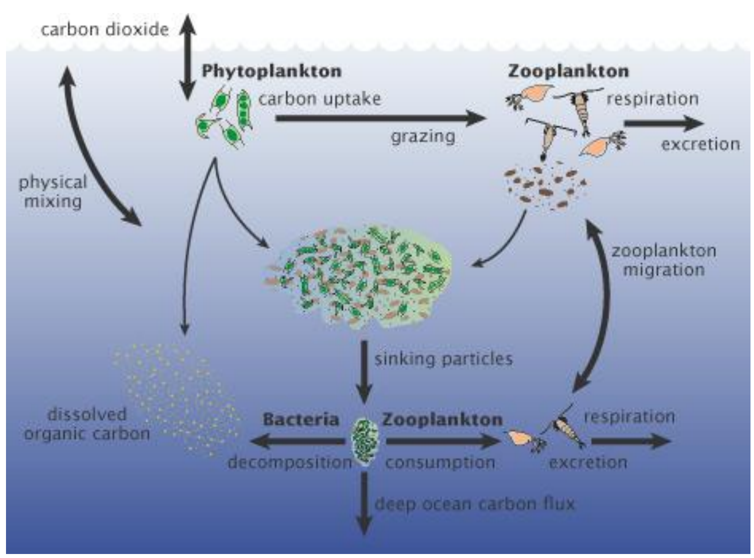
Phytoplankton can also be the harbingers of death or disease. Certain species of phytoplankton produce powerful biotoxins, making them responsible for so-called "red tides," or harmful algal blooms. These toxic blooms can kill marine life and people who eat contaminated seafood.

Phytoplankton cause mass mortality in other ways. In the aftermath of a massive bloom, dead phytoplankton sink to the ocean or lake floor. The bacteria that decompose the phytoplankton deplete the oxygen in the water, suffocating animal life; the result is a dead zone.

Dead fish washed onto a beach at Padre Island, Texas, in October 2009, following a red tide (harmful algal bloom). (Photo by qnr-away for a while)

Climate and the Carbon Cycle

Through photosynthesis, phytoplankton consume carbon dioxide on a scale equivalent to forests and other land plants. Some of this carbon is carried to the deep ocean when phytoplankton die, and some is transferred to different layers of the ocean as phytoplankton are eaten by other creatures, which themselves reproduce, generate waste, and die.



Phytoplankton are responsible for most of the transfer of carbon dioxide from the atmosphere to the ocean.

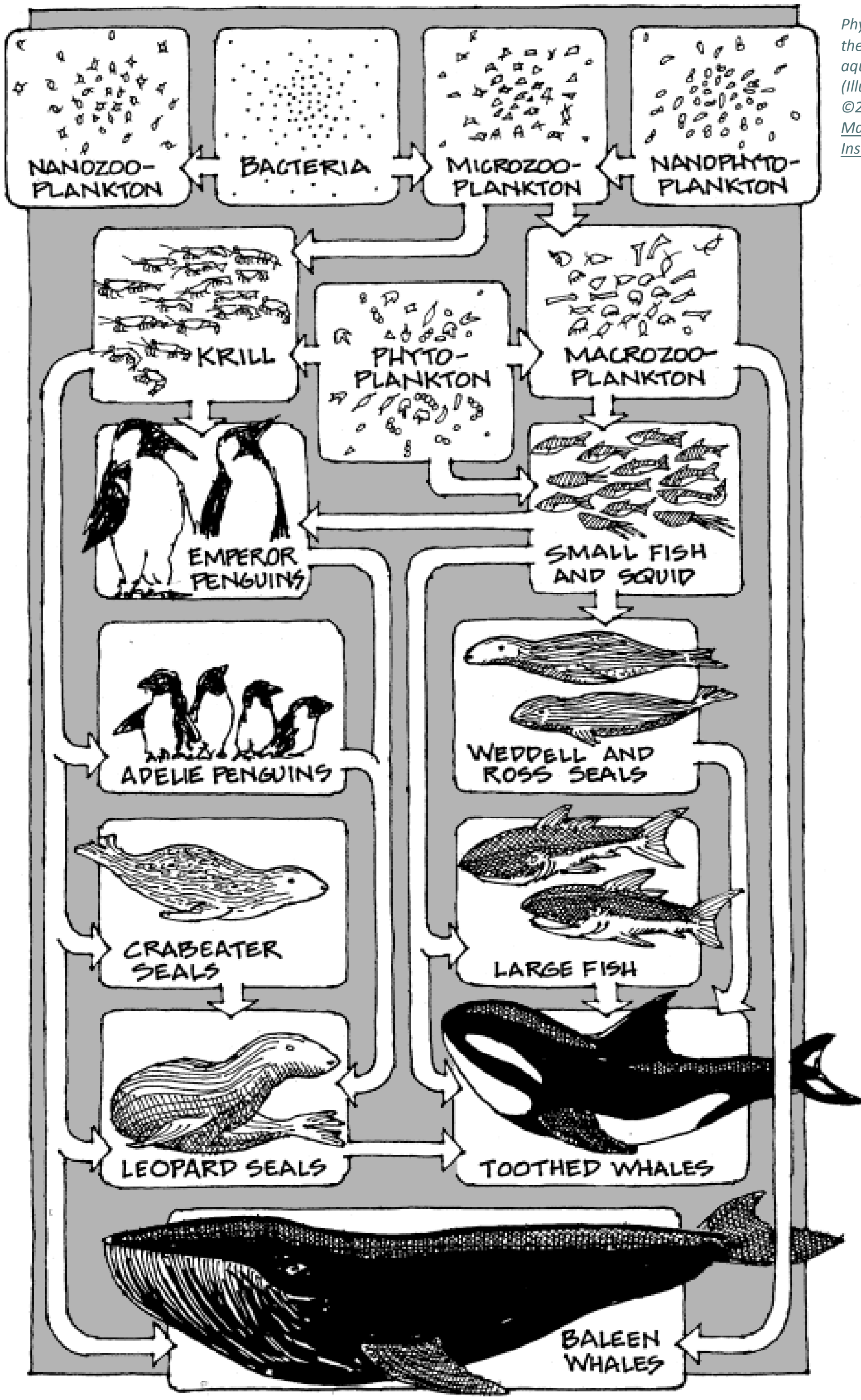
Carbon dioxide is consumed during photosynthesis, and the carbon is incorporated in the phytoplankton, just as carbon is stored in the wood and leaves of a tree.

Most of the carbon is returned to near-surface waters when phytoplankton are eaten or decompose, but some falls into the ocean depths.

(Illustration adapted from A New Wave of Ocean Science, U.S. JGOFS.)

Worldwide, this "biological carbon pump" transfers about 10 gigatonnes of carbon from the atmosphere to the deep ocean each year. Even small changes in the growth of phytoplankton may affect atmospheric carbon dioxide concentrations, which would feed back to global surface temperatures.

THE AQUATIC FOOD WEB



Phytoplankton form the base of the aquatic food web. (Illustration ©2010 Gulf of Maine Research Institute.)

Studying Phytoplankton

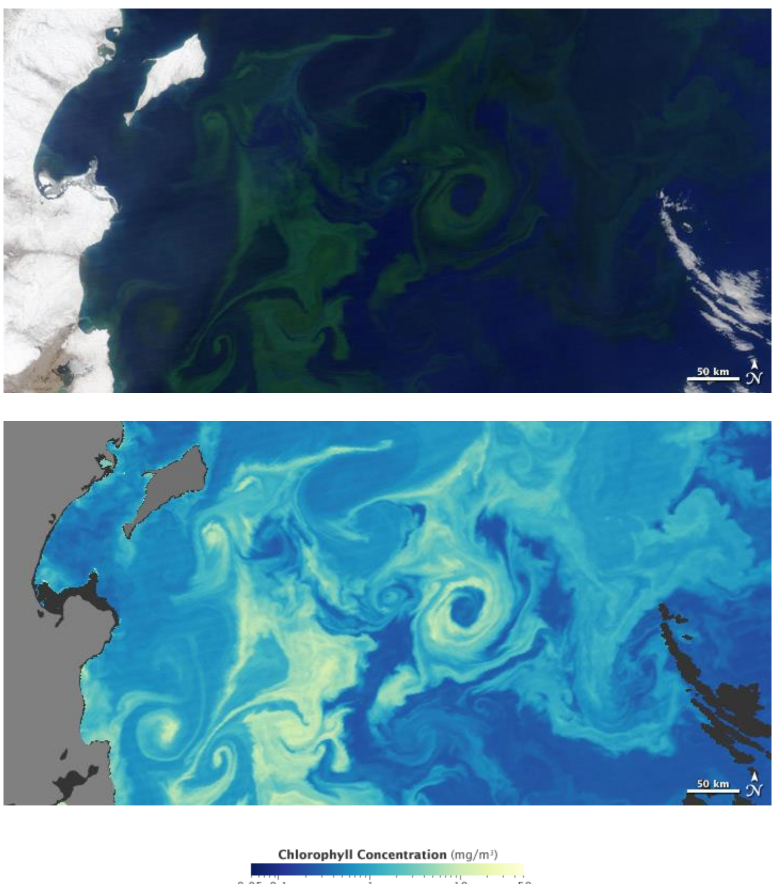
Phytoplankton samples can be taken directly from the water at permanent observation stations or from ships. Sampling devices include hoses and flasks to collect water samples, and sometimes, plankton are collected on filters dragged through the water behind a ship.

Marine biologists use plankton nets to sample phytoplankton directly from the ocean (Photograph ©2007 Ben Pittenger)

Samples may be sealed and put on ice and transported for laboratory analysis, where researchers may be able to identify the phytoplankton collected down to the genus or even species level through microscopic investigation or genetic analysis.

Although samples taken from the ocean are necessary for some studies, satellites are pivotal for global-scale studies of phytoplankton and their role in climate change. Individual phytoplankton are tiny, but when they bloom by the billions, the high concentrations of chlorophyll and other light-catching pigments change the way the surface reflects light.

The water may turn greenish, reddish, or brownish. The chalky scales that cover coccolithophores color the water milky white or bright blue. Scientists use these changes in ocean color to estimate chlorophyll concentration and the biomass of phytoplankton in the ocean.



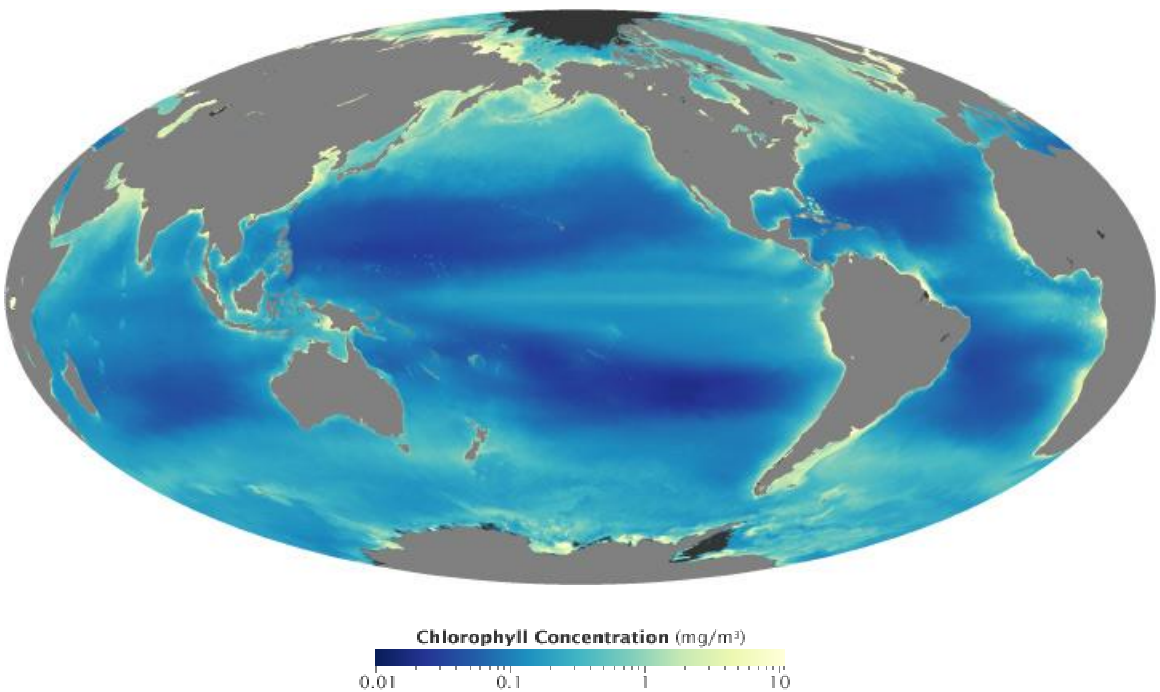
In natural-color satellite images (top), phytoplankton appear as colorful swirls. Scientists use these observations to estimate chlorophyll concentration (bottom) in the water. These images show a bloom near Kamchatka on June 2, 2010. (Images by Robert Simmon and Jesse Allen, based on <u>MODIS</u>data.)

GLOBAL PATTERNS AND CYCLES

Differences from place to place

Phytoplankton thrive along coastlines and continental shelves, along the equator in the Pacific and Atlantic Oceans, and in high-latitude areas. Winds play a strong role in the distribution of phytoplankton because they drive currents that cause deep water, loaded with nutrients, to be pulled up to the surface.

These upwelling zones, including one along the equator maintained by the convergence of the easterly trade winds, and others along the western coasts of several continents, are among the most productive ocean ecosystems. By contrast, phytoplankton are scarce in remote ocean gyres due to nutrient limitations.



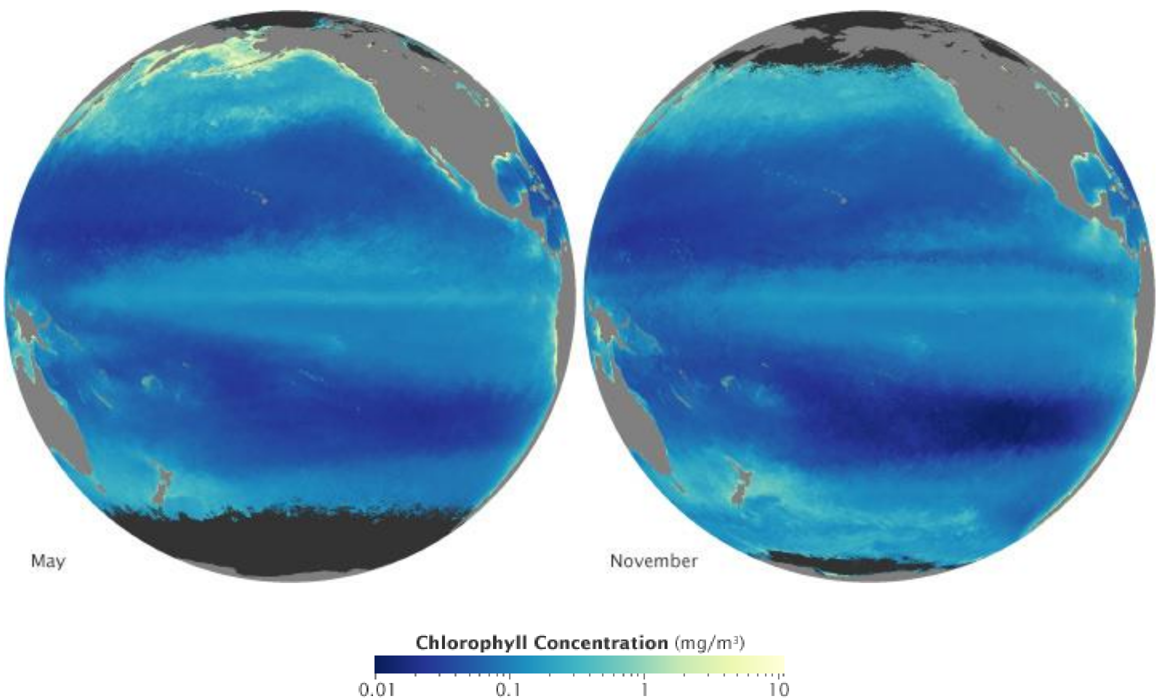
*Phytoplankton are most abundant (yellow, high chlorophyll) in high latitudes and in upwelling zones along the equator and near coastlines. They are scarce in remote oceans (dark blue), where nutrient levels are low. This map shows the average chlorophyll concentration in the global oceans from July 2002–May 2010. **View animation:** small (5 MB) large (18 MB). (NASA image by Jesse Allen & Robert Simmon, based on MODIS data from the GSFC Ocean Color team.)*

Differences from season to season

Like plants on land, phytoplankton growth varies seasonally. In high latitudes, blooms peak in the spring and summer, when sunlight increases and the relentless mixing of the water by winter storms subsides. Recent research suggests the vigorous winter mixing sets the stage for explosive spring growth by bringing nutrients up from deeper waters into the sunlit layers at the surface and separating phytoplankton from their zooplankton predators.

In the subtropical oceans, by contrast, phytoplankton populations drop off in summer. As surface waters warm up through the summer, they become very buoyant. With warm, buoyant water on top and cold, dense water below, the water column doesn't mix easily. Phytoplankton use up the nutrients available, and growth falls off until winter storms kick-start mixing.

In lower-latitude areas, including the Arabian Sea and the waters around Indonesia, seasonal blooms are often linked to monsoon-related changes in winds. As the winds reverse direction (offshore versus onshore), they alternately enhance or suppress upwelling, which changes nutrient concentrations. In the equatorial upwelling zone, there is very little seasonal change in phytoplankton productivity.

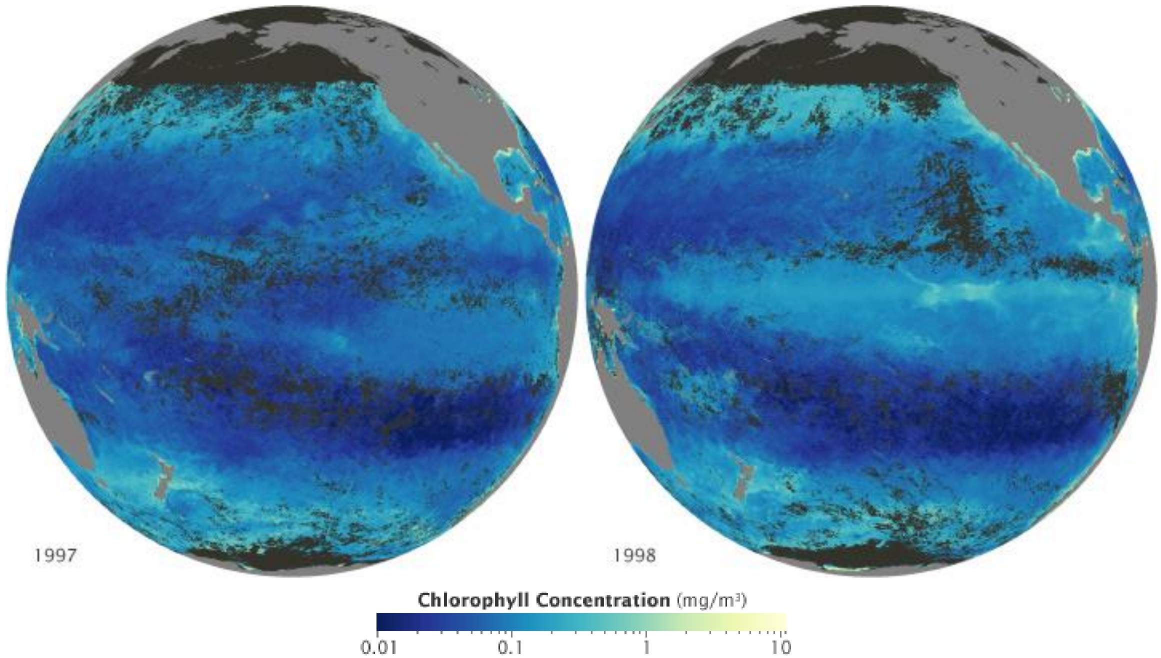


In spring and summer, phytoplankton bloom at high latitudes and decline in subtropical latitudes. These maps show average chlorophyll concentration in May 2003–2010 (left) and November 2002–2009 (right) in the Pacific Ocean. (NASA images by Jesse Allen & Robert Simmon, based on MODIS data from the GSFC Ocean Color team.)

Differences from year to year

The biggest influence on year-to-year differences in global phytoplankton productivity is the El Niño-Southern Oscillation (ENSO) climate pattern. ENSO cycles are significant changes from typical sea surface temperatures, wind patterns, and rainfall in the Pacific Ocean along the equator.

During EL Niño events, phytoplankton productivity in the equatorial Pacific declines dramatically as the easterly trade winds that normally drive upwelling grow still or even reverse direction. The transition between El Niño and its counterpart, La Niña, is sometimes accompanied by a dramatic surge in phytoplankton productivity as upwelling of nutrient-rich deep water is suddenly renewed.



During an El Niño (December 1997, left), upwelling in the equatorial Pacific slows, reducing phytoplankton density. In contrast, a La Niña increases upwelling in the same area, enhancing phytoplankton growth (December 1998, right). (NASA image by Jesse Allen & Robert Simmon, based on SeaWiFS data from the GSFC Ocean Color team.)

El Niño events influence weather patterns beyond the Pacific; in the eastern Indian Ocean around Indonesia, for example, phytoplankton productivity increases during El Niño. Productivity in the Gulf of Mexico and the western sub-tropical Atlantic has increased during El Niño events in the past decade, probably because increased rainfall and runoff delivered more nutrients than usual.

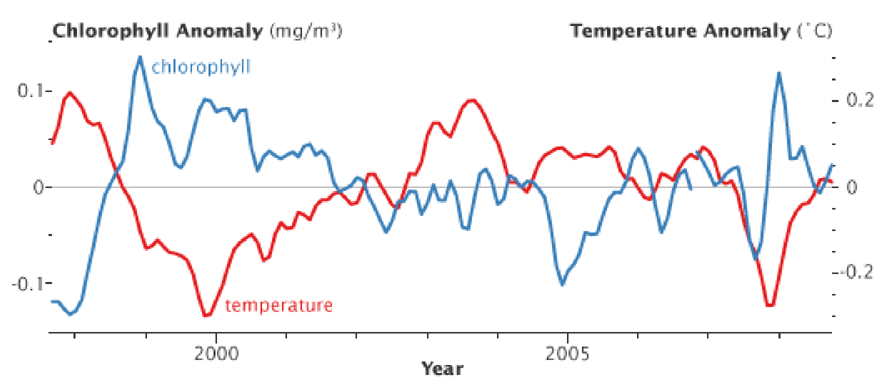
Compared to the ENSO-related changes in the productivity in the tropical Pacific, year-to-year differences in productivity in mid- and high latitudes are small.

LONG-TERM CHANGES IN PHYTOPLANKTON

Productivity

Because phytoplankton are so crucial to ocean biology and climate, any change in their productivity could have a significant influence on biodiversity, fisheries and the human food supply, and the pace of global warming.

Many models of ocean chemistry and biology predict that as the ocean surface warms in response to increasing atmospheric greenhouse gases, phytoplankton productivity will decline.



About 70% of the ocean is permanently stratified into layers that don't mix well. Between late 1997 and mid-2008, satellites observed that warmer-than-average temperatures (red line) led to below-average chlorophyll concentrations (blue line) in these areas. (Graph adapted

Productivity is expected to drop because as the surface waters warm, the water column becomes increasingly *stratified*; there is less vertical mixing to recycle nutrients from deep waters back to the surface.

Over the past decade, scientists have begun looking for this trend in satellite observations, and early studies suggest there has been a small decrease in global phytoplankton productivity. For example, ocean scientists documented an increase in the area of subtropical ocean gyres—the least productive ocean areas—over the past decade. These low-nutrient “marine deserts” appear to be expanding due to rising ocean surface temperatures.

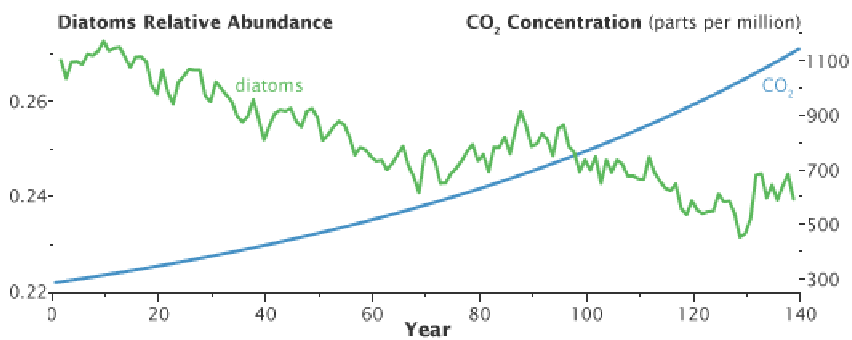
Species composition

Hundreds of thousands of species of phytoplankton live in Earth's oceans, each adapted to particular water conditions. Changes in water clarity, nutrient content, and salinity change the species that live in a given place.

Because larger plankton require more nutrients, they have a greater need for the vertical mixing of the water column that restocks depleted nutrients. As the ocean has warmed since the 1950s, it has become increasingly stratified, which cuts off nutrient recycling.

Continued warming due to the build up of carbon dioxide is predicted to reduce the amounts of larger phytoplankton such as diatoms), compared to smaller types, like cyanobacteria. Shifts in the relative abundance of larger versus smaller species of phytoplankton have been observed already in places around the world, but whether it will change overall productivity remains uncertain.

These shifts in species composition may be benign, or they may result in a cascade of negative consequences throughout the marine food web. Accurate global mapping of phytoplankton taxonomic groups is one of the primary goals of proposed future NASA missions like the Aerosol, Cloud, Ecology (ACE) mission.



As carbon dioxide concentrations (blue line) increase in the next century, oceans will become more stratified. As upwelling declines, populations of larger phytoplankton such as diatoms are predicted to decline (green line). (Graph adapted from Bopp 2005 by Robert Simmon.)

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