Phytoplankton

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Summary and Introduction

Phytoplankton play a key role in the marine ecology of the Gulf of the Farallones. These microscopic, single-celled plants are found in greatest abundance in nearshore coastal areas, typically within the upper 50 m (160 ft) of the water column. The name "phytoplankton" consists of two Greek words meaning "plant" (phyto) and "wanderer" (plankton). There are two major groups of phytoplankton—(1) fast-growing diatoms, which have no means to propel themselves through the water, and (2) flagellates and dinoflagellates, which can migrate vertically in the water column in response to light. Each group exhibits a tremendous variety of cell shapes, many with intricate designs and ornamentations.

All species of phytoplankton are at the mercy of oceanic currents for transport to areas that are suitable for their survival and growth. Thus, physical processes can play a significant role in determining the distribution of phytoplankton species. Rapid cell division and population growth in phytoplankton can produce millions of cells per liter of seawater, resulting in visible blooms or "red tides."

With the potential for such high productivity, it is not surprising that phytoplankton are the first link in nearly all marine food chains. Without phytoplankton, the diversity and abundance of marine life in the Gulf of the Farallones would be impossible. Phytoplankton provide food for a tremendous variety of organisms, including zooplankton (microscopic animals), bivalve molluscan shellfish (mussels, oysters, scallops, and clams), and small fish (such as anchovies and sardines). These animals, in turn, provide food for other animals, including crabs, starfish, fish, marine birds, marine mammals, and humans (fig. 1).

The coastal area of the Gulf of the Farallones undergoes periods of strong upwelling during the spring and summer months (see chapter on Current Patterns over the Continental Shelf and Slope). In addition to delivering colder, nutrient-rich waters from depth, coastal upwelling concentrates phytoplankton near the surface. This concentration of cells in sunlit surface waters, together with increased nutrients, may provide a competitive edge for the faster growing diatoms during upwelling events. Conversely, a stratified water mass consisting of a layer of warmer surface water and a deeper layer of colder, nutrient-rich water can form following upwelling. These conditions favor the development of dinoflagellate blooms, such as toxic "red tides," because these types of phytoplankton can actively swim to the surface to photosynthesize during the day and migrate to deeper areas at night to absorb nutrients. Such conditions can also be associated with downwelling, in which warmer offshore waters move shoreward, pushing coastal surface waters down and along the sea floor to deeper areas. Research in other parts of the world has shown that dinoflagellates are commonly associated with such nearshore downwelling.

Of the more than 5,000 known species of marine phytoplankton, approximately 40 species worldwide have been linked with production of toxins. These marine biotoxins can have subtle to lethal effects on various forms of marine life. Human consumers of certain seafood items (especially clams, oysters, and mussels) are also at risk. It remains difficult to avoid the harmful effects associated with blooms of these toxic species because phytoplankton ecology is not fully understood.

Within the Gulf of the Farallones, red tides are a common natural phenomenon, usually occurring from August through October, when a relaxation of coastal upwelling results in a warmer, more stable water mass nearshore that appears to favor dinoflagellate populations. The commonly used term "red tide" is misleading, because phytoplankton blooms frequently are other colors, such as brown, green, and yellow, and are in any case not a tidal phenomenon.

Nearly all phytoplankton blooms along the California coast and within the Gulf of the Farallones involve nontoxigenic species. Conversely, most incidents of paralytic shellfish poisoning (PSP) in humans caused by eating shellfish caught in California waters have occurred in the absence of visible blooms of toxin-producing phytoplankton. Because the coastal area encompassed by the marine sanctuary has been the focal point for PSP toxicity in California, and because of the continued increase in commercial bivalve shellfish aquaculture within this area, the California Department of Health Services has intensified its biotoxin-monitoring efforts in the area.

The key to understanding the combination of physical, chemical, and biological factors that result in blooms of the phytoplankton species that produce PSP toxins may lie within the Gulf of the Farallones. Such understanding would greatly assist in the protection of public health.

Phytoplankton Biology

There are two major groups of phytoplankton: (1) nonmotile, fast-growing diatoms; and (2) motile flagellates and dinoflagellates, which can migrate vertically in the water column in response to light. Each group exhibits a tremendous variety of cell shapes, many with intricate designs and ornamentations (figs. 2–5). The diatoms are further divided into two groups based on cell shape: (1) Pennate diatoms, which evolved first during the Late Cretaceous, are long and flat; and (2) centric diatoms, which evolved later than the pennates, are shaped like pillboxes and may have elaborate arrays of spines projecting from their cell walls.

Phytoplankton vary widely in physical and chemical requirements for population growth. Diatoms and dinoflagellates also differ significantly with respect to motility, cell-wall composition and ornamentation, and nutritional and reproductive strategies.

Diatoms have cell walls, called frustules, made of silica (the same material in glass and opal). In contrast, dinoflagellates can have a rigid cell wall, called a theca, made of cellulose plates, or they can have a nonrigid cell membrane (no theca). These two forms of dinoflagellate structures gave rise to the terms "armored" and "unarmored" (or "naked") dinoflagellates. Diatoms and dinoflagellates can be highly ornamented, which aids in species identification. Cell-surface designs on some diatoms may help focus light on chloroplasts, allowing survival at greater depths where light intensity is very low. Long spines, cell shape, and the formation of chains and colonies make diatoms more difficult for predators to grasp or bite and also assist in flotation. Some dinoflagellates form chains, whereas others have protuberances that look like wings, crowns, or horns, for similar reasons.

Both groups commonly reproduce by simple cell division. Some species of diatoms and dinoflagellates are known to produce resting stages. Resting spores in diatoms, and cysts in dinoflagellates, allow species to survive in unfavorable conditions. Some diatoms form specialized sexual-reproductive structures called auxospores that look like greatly enlarged versions of normal vegetative cells. Dinoflagellates have motile sexual phases that may become cysts or normal vegetative cells, depending on prevailing conditions.

Although all species of dinoflagellates and diatoms share certain basic requirements for growth (light, carbon dioxide, nutrients, trace elements, habitable temperature and salinity), they can differ considerably in their optimal requirements for these factors. Nutritionally, diatoms rely solely on photosynthesis as a source of energy; they cannot survive if they are transported below the photic zone. Dinoflagellates, in contrast, have several survival strategies, ranging from photosynthesis to predation and parasitism. Some dinoflagellate species have feeding veils that are extruded around such food items as diatoms. Both groups are able to absorb nutrients and vitamins into the cell and have distinct preferences for the forms of some of those nutrients. In addition, chelating agents (compounds that attract trace metal ions), such as those derived from humic material, have been shown to be beneficial for phytoplankton growth. Not surprisingly, then, red tides (see next section) in different parts of the world commonly have been associated with rainfall-related land and river runoff. Silica is a limiting factor for diatom growth, whereas nitrogen and phosphorus can be limiting factors for dinoflagellate growth.

Transport

The name "phytoplankton" consists of two Greek words meaning "plant" (phyto) and "wanderer" (plankton). All species of phytoplankton are at the mercy of oceanic currents for transport to areas that are suitable for their survival and growth. Thus, physical processes can play a significant role in determining the composition and distribution of phytoplankton species, and they are an important factor in the development of blooms. Areas of strong mixing and movement discourage the concentration of cells or may physically disrupt an existing bloom. Calm seas and stable water masses are conducive to the concentration of cells.

The coastal area within Gulf of the Farallones National Marine Sanctuary undergoes periods of strong upwelling during the spring and summer months (see chapter on Current Patterns over the Continental Shelf and Slope). In addition to delivering colder, nutrient-rich waters from depth (fig. 6), coastal upwelling physically concentrates phytoplankton near the surface. This concentration of cells in the upper photic zone, together with increased nutrients, may provide a competitive edge for the faster-growing diatoms during upwelling events. Conversely, a period of relaxation following upwelling can result in a stratified water mass consisting of a layer of calm, warmer surface water and a deeper layer of colder, nutrient-rich water (fig. 7). These conditions favor the development of dinoflagellate blooms, called "red tides," because these types of phytoplankton can actively swim to the surface to photosynthesize during the day and migrate to deeper areas at night to absorb nutrients. Relaxation events can also be associated with downwelling, where warmer offshore waters are advected nearshore, pushing coastal surface waters down along the sea floor to deeper areas (see chapter on Current Patterns over the Continental Shelf and Slope). Researchers in other parts of the world have shown that dinoflagellates are commonly associated with these warm-water fronts that are advected nearshore.

Blooms, Red Tides, and Toxicity

Phytoplankton blooms in general, and toxic blooms in particular, have been increasing in frequency and distribution worldwide since the 1980's. Although the reasons for this apparent increase are unclear, several have been suggested: (1) increased nutrient input to coastal oceans from human activities, (2) large-scale climactic changes (for example, global warming), (3) transport of toxigenic species in ship ballast water, (4) increased use of coastal resources for shellfish harvesting and aquaculture, and (5) increased surveillance by government health agencies and researchers.

The commonly used term “red tide” is quite misleading because phytoplankton blooms frequently are other colors (brown, green, even yellow) and are not a tidal phenomenon. Although diatoms are more numerous than dinoflagellates in terms of number of species, the dinoflagellates are associated with worldwide occurrences of red tides. A unique characteristic of some red tides is the phenomenon of bioluminescence. Light produced by some species of dinoflagellates (*Noctiluca scintillans, Lingulodinium polyedra*) can actually illuminate the waves and surface of the ocean under bloom conditions. Red tides are a common phenomenon in the Gulf of the Farallones, occurring typically from the end of summer into fall (August through October), when a relaxation of coastal upwelling results in a warmer, more stable water mass nearshore that appears to favor dinoflagellate populations. Phytoplankton monitoring conducted by the California Department of Health Services (CDHS) since the mid-1990’s has documented patterns of species composition and distribution that are consistent with these relations. Data from areas of conspicuous upwelling, such as the marine sanctuary, show that diatoms are by far the most numerous and abundant species during these events. Relaxation of upwelling for extended periods has been strongly associated with the emergence of dinoflagellates as the dominant group. One such extended relaxation event in summer and fall 1995 resulted in a long-lasting visible bloom of dinoflagellates throughout the marine sanctuary. *Gymnodinium splendens*, a nontoxic species, was dominant for almost 2 months before another species replaced it. Nearly all phytoplankton blooms along the California coast and within the Gulf of the Farallones involve nontoxigenic species. Conversely, nearly all incidents of paralytic shellfish poisoning (PSP) toxicity in shellfish have occurred in the absence of visible blooms of toxin-producing phytoplankton.

Some species of phytoplankton can have harmful effects on organisms at different trophic levels. Blooms of some otherwise-harmless species result in massive fishkills by depleting dissolved oxygen or by clogging the gills of fish. Within the Gulf of the Farallones, the phytoplankton species that pose the greatest risk to marine life, and to the humans who harvest various organisms within it, are those that produce marine biotoxins. These natural toxins are concentrated in different species at different trophic levels. Bivalve shellfish (mussels, clams, scallops, oysters) and fish (anchovy, sardine) that consume phytoplankton concentrate marine biotoxins, increasing the danger to the next level of consumers (larger fish, seabirds, marine mammals, humans).

Of the five major groups of marine biotoxins known worldwide, two are known to occur along the California coast. The PSP toxins, produced by the dinoflagellate *Alexandrium catenella* (fig. 8), have long been associated with bivalve shellfish in California. The other known toxin, domoic acid, was first identified along the Pacific coast of the United States in 1991. Produced by the diatom *Pseudonitzschia australis* (fig. 9), domoic acid was responsible for the deaths of hundreds of brown pelicans and cormorants that fed on toxic anchovy in Monterey Bay.

The focal point for the occurrence of PSP toxins has historically been along the Marin County coast north of San Francisco, an area within the Gulf of the Farallones. The occurrence of *Alexandrium*, followed by the rapid accumulation of PSP toxins in bivalve shellfish, frequently originates in the southern Marin County coast near Drakes Bay. Large-scale episodes of PSP toxicity appear to involve a northward progression of toxicity, extending as far north as the Del Norte County coast near the California-Oregon State line. The CDHS’ Marine Biotoxin

Monitoring and Control Program, which has been monitoring bivalve shellfish along the California coast for many decades, maintains several stations within the marine sanctuary. In 1992, a volunteer-based phytoplankton-monitoring program was also begun. Data from the frequent collection and identification of phytoplankton along the coast are providing valuable information on the spatial and temporal distribution of toxigenic phytoplankton. In addition, satellite imagery of sea-surface temperatures, coupled with buoy data on temperatures and windspeed and wind direction, provides information on the sites of upwelling or relaxation events and on the movement of water masses. A combination of these sources of data has allowed the State to anticipate toxic blooms in several areas.

Conclusion

Within the Gulf of the Farallones, as elsewhere, phytoplankton are critical to the survival and growth of many species of marine life. At certain times, the occurrence of a toxin-producing species of phytoplankton may affect wildlife, causing illness or death. Human consumers of certain seafood items (especially bivalve shellfish) are also at risk in the absence of adequate monitoring programs. Our ability to understand and predict these natural events would greatly assist in the protection of public health. Because the coastal area encompassed by the gulf has been the focal point for PSP toxicity in California, and because of the continued increase in commercial bivalve shellfish aquaculture within this area, CDHS has intensified its biotoxin-monitoring efforts in the area. The key to understanding the combination of physical, chemical, and biological factors that result in blooms of the phytoplankton species which produces PSP toxins may lie within the Gulf of the Farallones.

Further Reading

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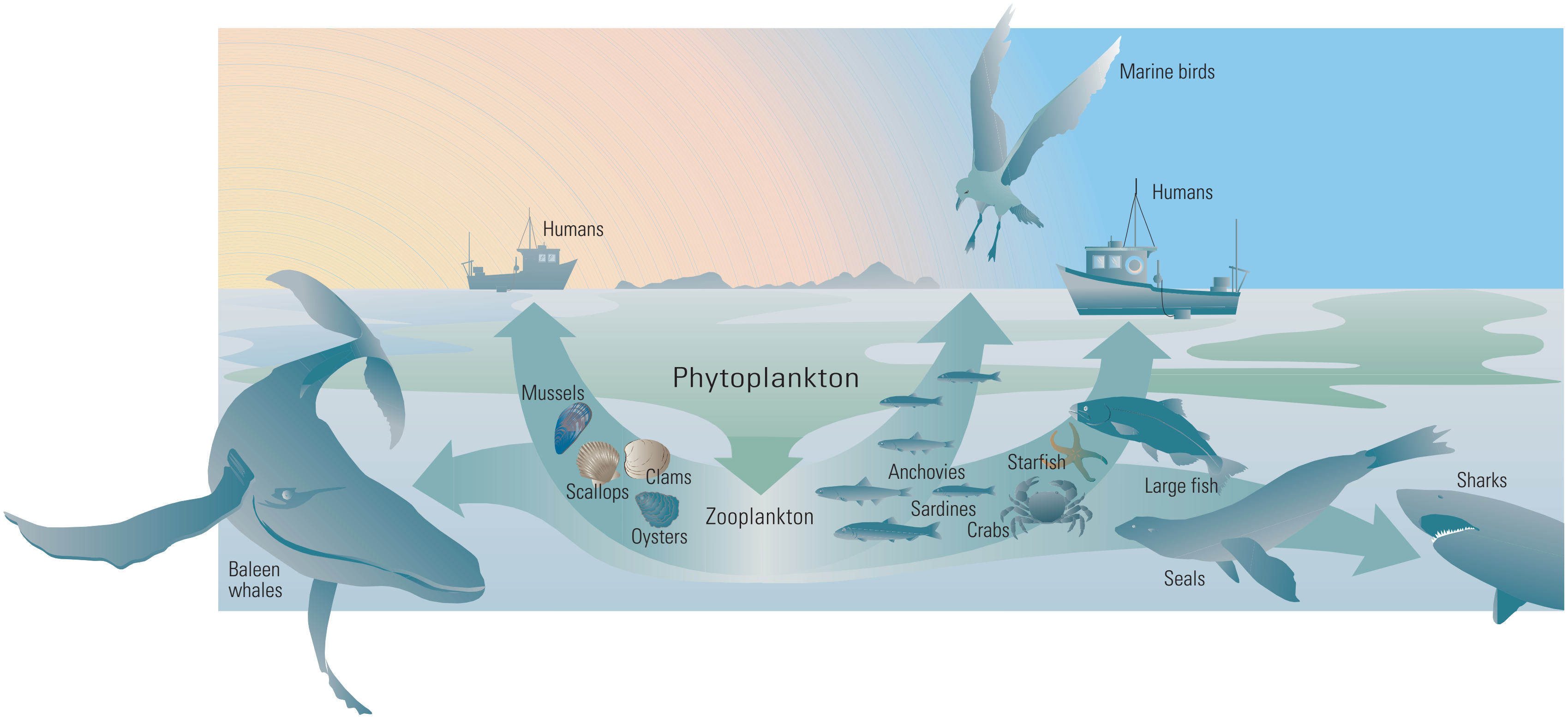

Figure 1. Simplified diagram of the food web in the Gulf of the Farallones.

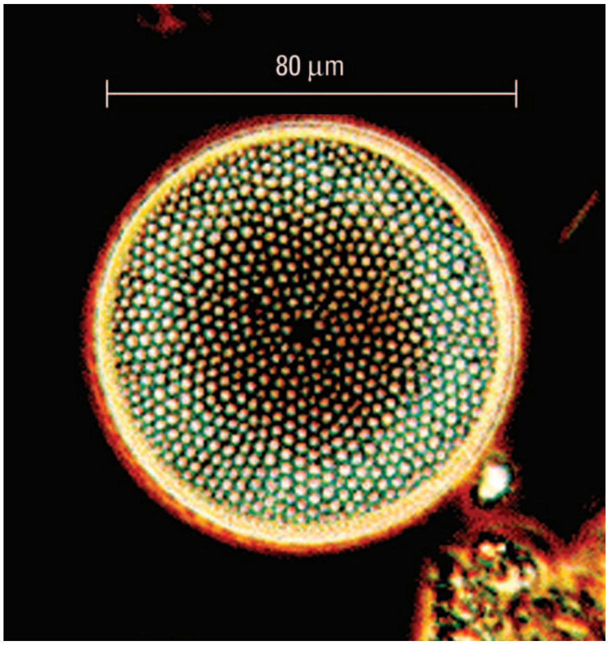

Figure 2. Photomicrograph of *Coscinodiscus*, a centric diatom.

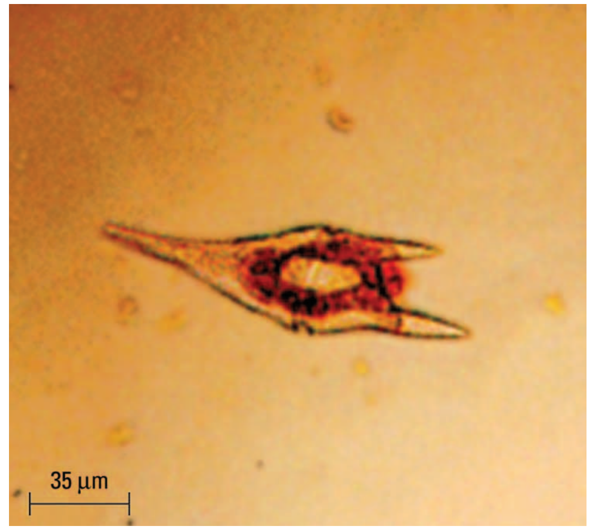

Figure 4. Photomicrograph of *Ceratium*, an armored dinoflagellate.

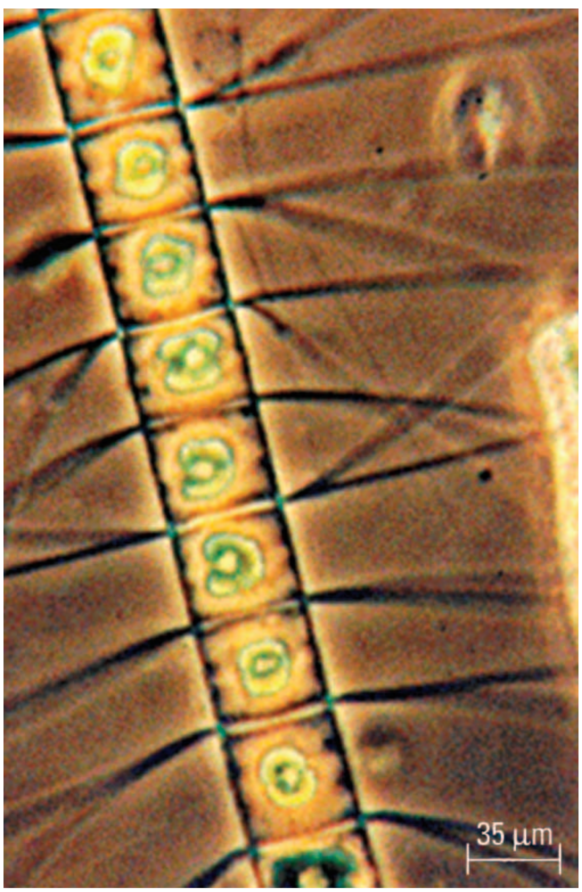

Figure 3. Photomicrograph of *Chaetoceros*, a chain-forming centric diatom.

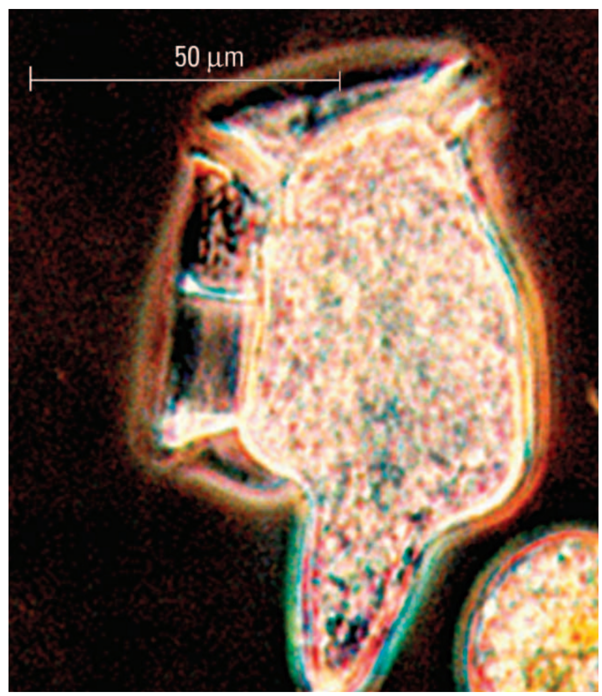

Figure 5. Photomicrograph of *Dinophysis*, an armored dinoflagellate, some species of which produce diarrhetic-shellfish-poisoning toxins.

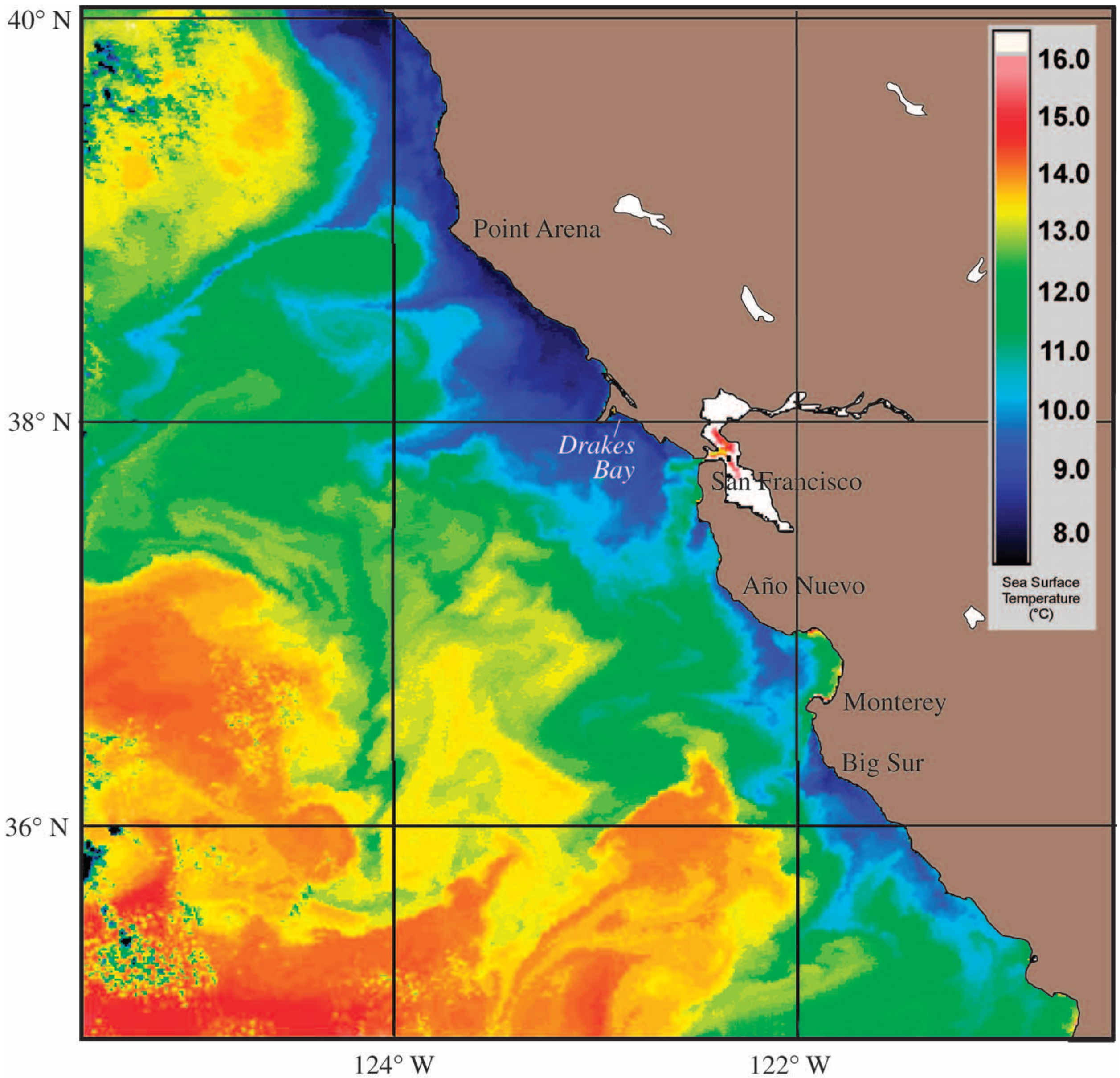

Figure 6. Advanced Very High Resolution Radiometry (AVHRR) satellite image, showing sea-surface temperature for central California during a period of upwelling. Strong upwelling is visible from Drakes Bay northward, as well as at Año Nuevo and Big Sur.

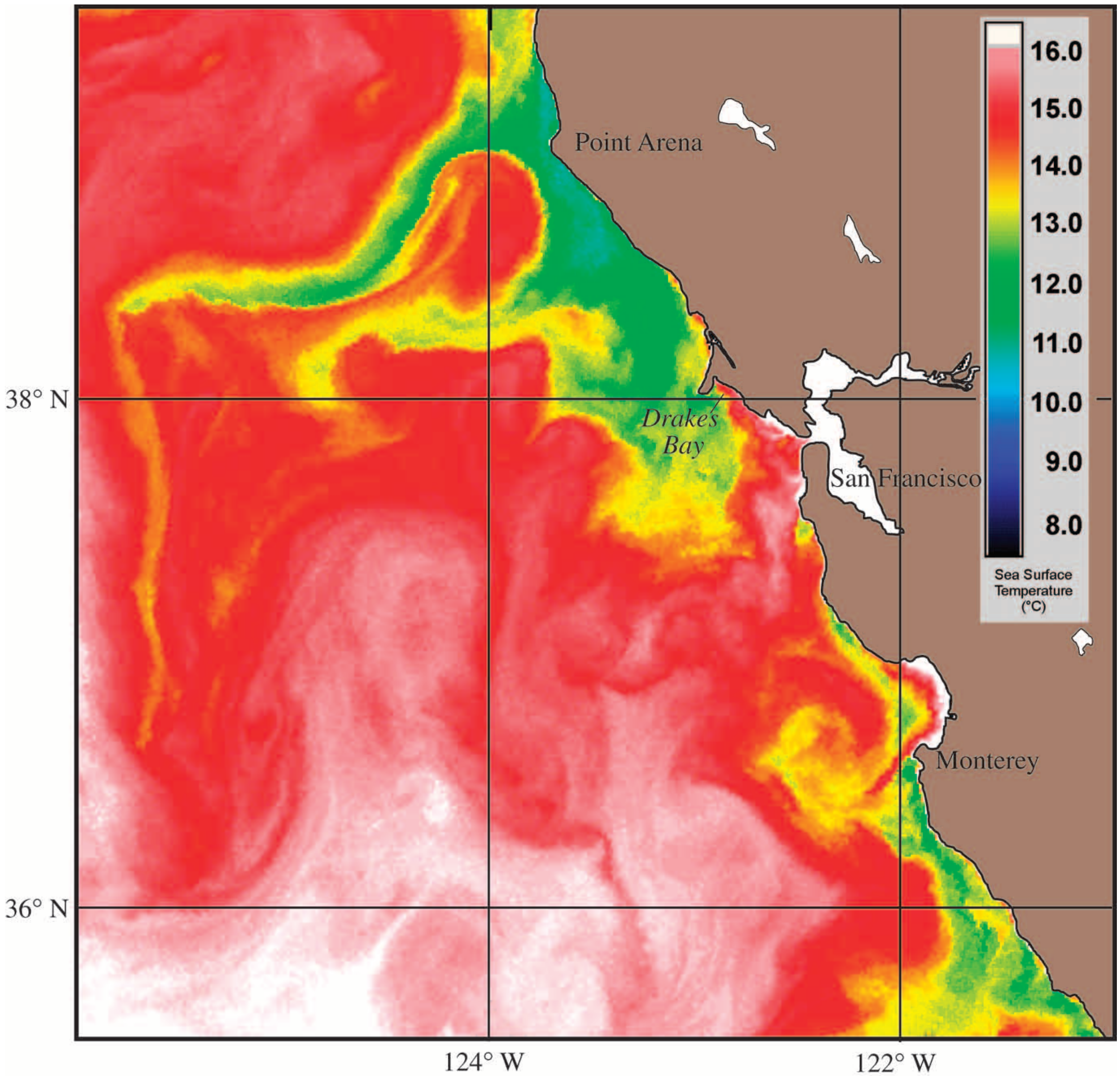

Figure 7. Advanced Very High Resolution Radiometry (AVHRR) satellite image, showing sea-surface temperature for central California during a period of relaxation following upwelling. In absence of upwelling, warm water has moved nearshore near the Golden Gate and into Drakes Bay.

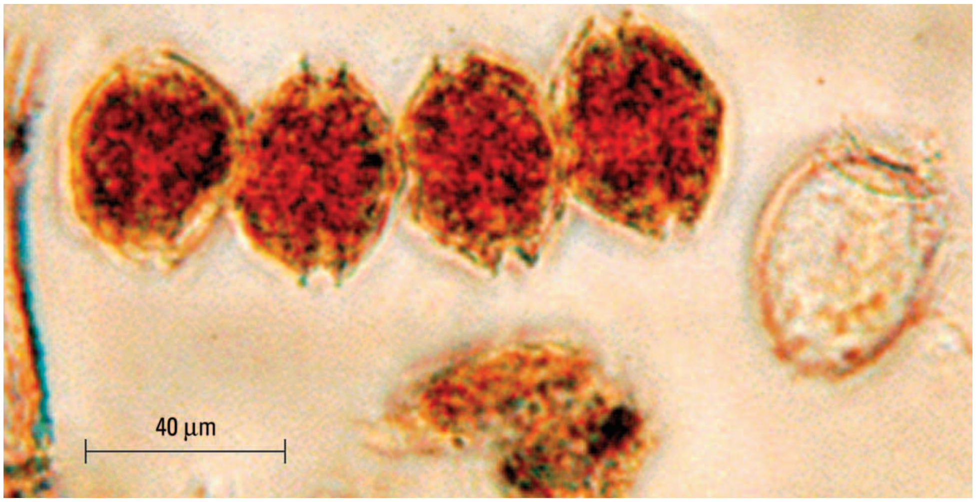

Figure 8. Photomicrograph of *Alexandrium catenella*, armored dinoflagellate responsible for production of paralytic-shellfish-poisoning toxins.

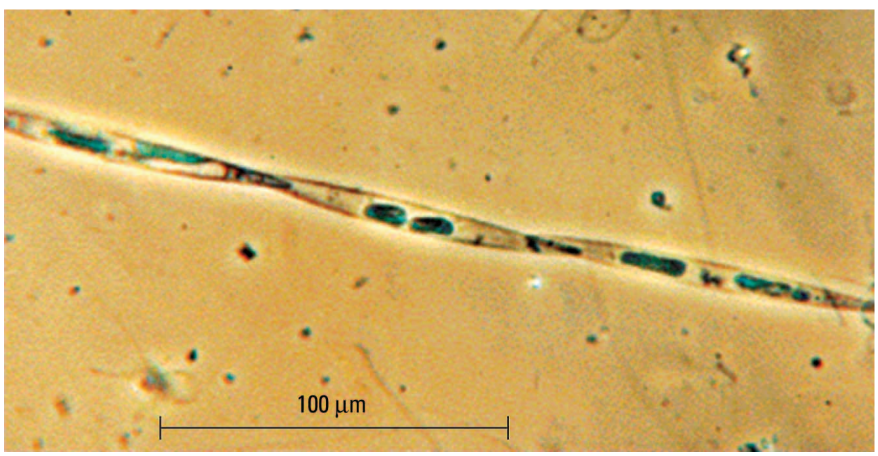

Figure 9. Photomicrograph of *Pseudonitzschia*, diatom responsible for production of domoic acid, which can cause amnesic shellfish poisoning in humans.