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Marine Plankton Food Webs and Climate Change

Plankton Food Webs

Estuarine and coastal marine food webs are dominated by plankton—organisms that drift with the currents. Composed of phytoplankton – photosynthetic microscopic algae; zooplankton – animals that eat phytoplankton or each other; and bacterioplankton – microbes that degrade organic matter, plankton exist in an ever-changing aquatic environment that requires them to respond quickly to changes in their habitat – on the time scales of days to weeks. The plankton are thus often the first to be impacted by climate change.

Harmful Algal Blooms

Many types of phytoplankton can grow and reach high numbers when nutrients (nitrogen (N) and phosphorus (P)) are added by human activities. When this happens, it is termed a “harmful algal bloom” or HAB. HABs often have high concentrations of toxic compounds that can accumulate in or kill filter feeding organisms. If people eat the filter feeders (for example, oysters), illness or death can result. HABs have occurred throughout history, but their numbers and frequency have greatly increased in the past 30 years, most likely due to higher N and P loads to coastal waters.² HABs have been noted in upper Chesapeake waters for some time³ (Figures 2, 3 on next page), and recently have occurred in the lower Chesapeake as well. The economic impacts of HABs are substantial; the *Alexandrium* bloom in New England in 2003 was estimated to cost the region ca. \$50 million, and a similar figure was estimated for the *Pfisteria* outbreak in Chesapeake Bay in 1997. Annually HABs cause approximately \$40 million in reductions in fisheries and shellfish harvests and declines in tourist activities, and this number will very likely increase in the future. All of these changes in phytoplankton result in changes in both zoo- and bacterioplankton. Effects of HABs on the food web can be mitigated by zooplankton grazers, which have varying susceptibility to HAB toxins.⁴ Furthermore, HAB species, by virtue of their high abundance, often severely reduce the oxygen present in the water at night, and cause physiological damage to other species.

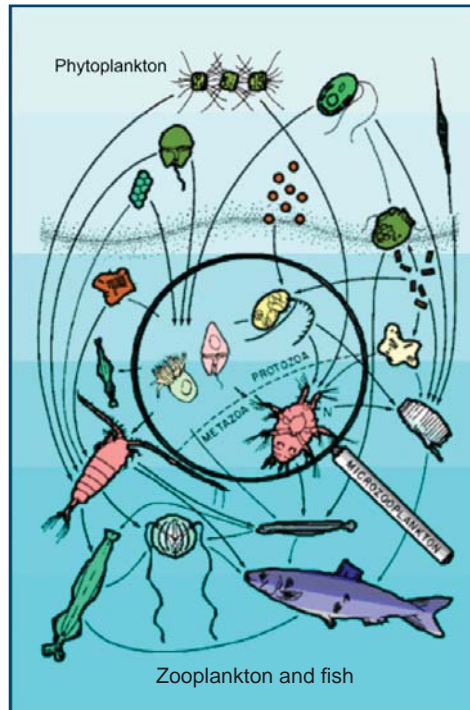


Figure 1. Example of a plankton food web.

Likely impacts of climate change on plankton in estuaries and coastal systems:

- Some plankton, such as diatoms, grow better at cooler temperatures. Warming may cause other, less palatable, species to replace them, depriving zooplankton and menhaden of their primary food source.
- Because phytoplankton are linked to freshwater and nutrient inputs, drought will likely decrease their abundance. Also, when nutrients are reduced, smaller phytoplankton replace diatoms, and the altered size impacts the entire food web. Changes in precipitation will have a major impact on estuarine plankton.
- Increases in carbon dioxide (CO₂) affect the growth of certain species, but not all species are impacted the same.¹ Some algae, such as Cyanobacteria, are favored under higher temperatures and CO₂ concentrations. Cyanobacteria can form noxious blooms (see Figure 2); therefore, CO₂ changes will likely create changes in the composition of plankton, which will cascade throughout the food web.



A dinoflagellate, a type of phytoplankton that forms harmful algal blooms.

Climate shifts will change not only the abundance and growth rates of species in estuarine and coastal environments, but likely result in a shift in the type of species present, with unknown consequences to the food web.

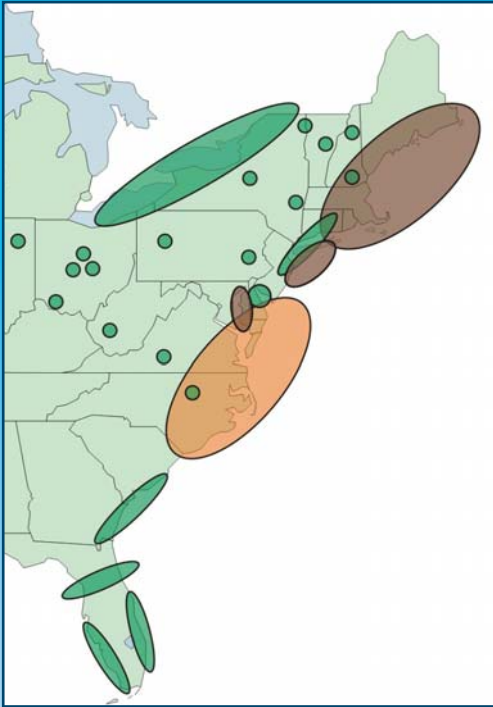


Figure 2. Distribution of harmful algal blooms on the east coast of the U.S. The orange area represents blooms of *Pfiesteria* and *Karlodinium*; green areas cyanobacterial blooms; brown areas brown tides. Human health impacts from paralytic shellfish poisoning (red) and *Pfiesteria* have occurred in the past 10 years. Based on <http://www.who.edu/redtide/page.do?pid=9257>.



Figure 3. A harmful algal bloom (HAB) in the Elizabeth River, Chesapeake Bay. Photo by L. Killberg.

Changes in Jellyfish

Another example of climate and human-induced shifts in food webs is the large increase in jellyfish populations that have occurred in coastal and estuarine ecosystems worldwide.⁵ The increase may be in response to increases in nutrients that stimulate phytoplankton, which in turn stimulate other zooplankton such as copepods (the major food source of jellyfish). An alternate explanation is that overfishing decreases plankton-eating fish populations, the jellyfish's major competitor for food, allowing jellyfish to increase in numbers. A striking seasonal change in the zooplankton of Chesapeake Bay is the increased abundance of jellyfish in summer months, such as sea nettles and comb jellies (Figure 4). Sea nettles are a species of jellyfish that stings humans, causing a painful irritation that can only be partially treated. Other forms such as comb jellies do not sting, but also compete for food against commercially important fish. Due to temperature increases in Chesapeake Bay, comb jellies are developing one-month earlier than they did 40 years ago, with unknown consequences for the food web (Figure 5).⁶ Given that both sea nettles and comb jellies are voracious eaters, it is expected that the copepods they feed on will be greatly reduced in numbers thus stressing other animals, such as Bay anchovy or striped bass, that depend on copepods for food.

Changes in Bacterioplankton

Bacterioplankton change as well, although their functional roles are likely to remain similar, even if their standing stocks increase (which also results in an increased oxygen demand within the water column). Lomas suggested that changes in bacterial abundance will be substantially larger than those of phytoplankton under conditions of future temperature increases.⁷ The types of bacteria present may also change, and that certain human pathogens might flourish relative to other bacterioplankton, thereby impacting human use of the estuary.

Changes in Timing of Natural Cycles

Climate change is also likely to alter the timing of natural events. As mentioned previously, diatoms often bloom in winter when temperatures are low. Zooplankton, because their life history is controlled by temperature, often lag behind the phytoplankton. This time delay structures the estuary and coastal system, providing energy to bottom-dwelling communities through the sinking of dead phytoplankton. As temperatures increase, zooplankton reproductive rates will increase, reducing the delay between phyto- and zooplankton blooms. If phytoplankton become more tightly "coupled" to zooplankton, inputs to the benthos may be altered, modifying energy flow within estuarine and coastal food webs.

Summary of Climate Impacts on Coastal Plankton

In the near future, changes in environmental variables such as nutrients, temperature, salinity, and CO₂ concentrations can be expected to

- Change not only the abundance and growth rates of plankton species in estuarine and coastal environments, but likely result in a shift in the type of species present, with unknown consequences to the food web;
- Produce interactive effects resulting in perturbations that far exceed changes in one variable;
- Increase the growth and accumulation of noxious species (such as harmful algae and jellyfish), with severe attendant socioeconomic and human health impacts;
- Alter the timing of natural events will be altered, with significant impacts on estuarine and coastal food webs.
- Economically important species will be influenced directly by climate-induced changes in plankton.

Key Future Climate Change Issues: Plankton

While many of the impacts of climate change on estuarine and coastal plankton are broadly known, far too little is known concerning the specific mechanisms of how these changes will occur. Four major questions need to be addressed by focused

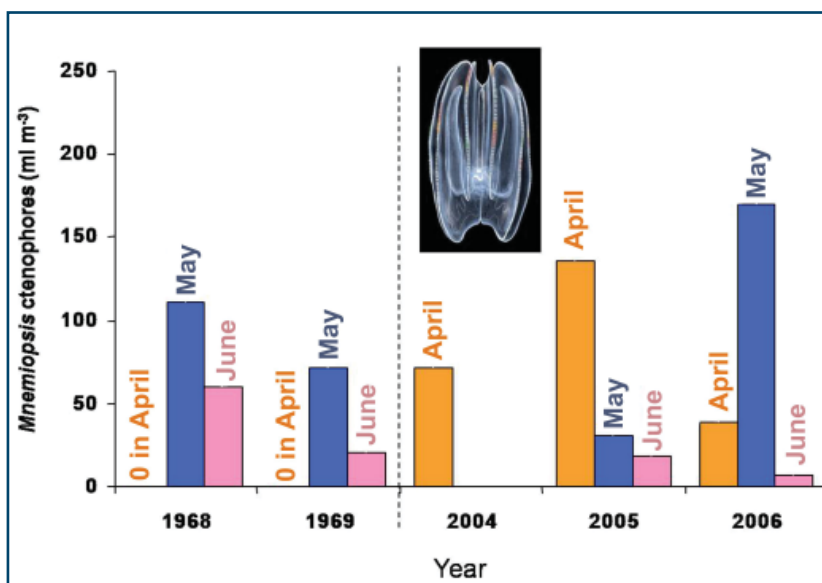


Figure 5. Blooms of comb jellies (the ctenophore *Mnemiopsis leidyi*, shown in insert) are presently occurring one month earlier than they did 40 yrs. ago, most likely due to rising seawater temperature which allows ctenophores to reproduce earlier. Comb jellies consume zooplankton, thus could potentially deprive fish of food. From Condon and Steinberg, in press.



Figure 4. A sea nettle (*Chrysaora quinquecirrha*), a species of zooplankton that forms large accumulations in Chesapeake Bay. They become extremely abundant and grow rapidly when water temperatures exceed 25°C. They are noxious in that they sting and are harmful to humans. There is no effective means to reduce their abundance. From <http://www.bbep.org/jellyfish.html>

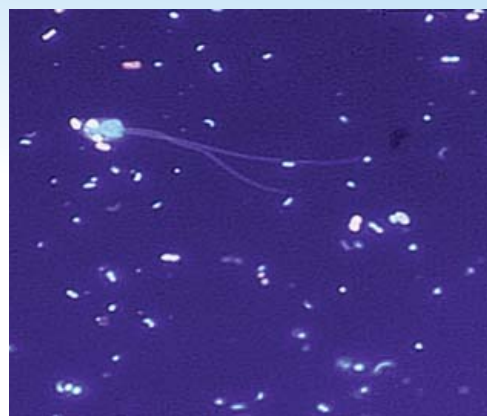


Figure 6. Marine bacteria cells (small glowing dots) which are 1/1000 mm in size. A small flagellate (larger cell with flagella) animal that feeds on bacterioplankton is also shown. Photo by C. Carlson.



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research in order to aid the Commonwealth in its goals to understand, mitigate, and predict the impacts of climate change in its waters:

1. What are the effects of altered environmental regimes in the control of phytoplankton growth and accumulation?
2. Will climate change induce larger, more extensive, and more damaging HABs, and if so, what are the proximal causes?
3. How will climatically altered environmental parameters (nutrient, salinity, CO₂) and changes in phytoplankton affect zooplankton reproduction and composition?
4. What effects do climate-induced changes in the plankton have on higher trophic levels and commercially important fish?

Likely Social and Economic Consequences

Climate change will bring to the Commonwealth associated costs, some of which can be predicted, but others which at this time cannot. It is predictable with a large degree of certainty that temperature and environmental (nutrient, salinity, CO₂) changes will result in an altered plankton community, and that this change will likely degrade the socioeconomic "return" from the estuary and coast by decreasing yield of harvestable species and altering the human life styles dependent on those. It is also probable that HABs will increase in magnitude, duration, and distribution, and that there will be a substantial, negative economic impact on the Commonwealth. Although economic models have not assessed this loss, it can be expected that it will annually be from \$3-10 million dollars per year in terms of lost harvests of certain species. Loss of tourism via the growth of noxious organisms (HABs, jellyfish) will also be significant, especially if such blooms begin to significantly expand into coastal waters.

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