POSSIBLE EFFECTS OF GLOBAL WARMING ON BIOLOGICAL PROCESSES IN THE OCEAN

Allan Michael
5 Field Rd.
Magnolia MA 01930
michael@cove.com

Stratification of the water column – it's all about nutrients
A small change could have big consequences

Productivity by plankton = production in fisheries

Long-term integrative monitoring – the key to understanding changes and verifying models

Fisheries Management: the challenges of including another variable
Predictions could avoid crashes

Introduction - The Gulf of Maine Ecosystem

The Gulf of Maine is a very complex and productive ecosystem. Although there are many differing habitats ranging from rocky bottom to mud and sand, biological processes are intertwined and heavily reliant on the fundamental physical properties of the system.

Nutrients and food are limiting for all levels of biological components in the ocean from the smallest planktonic species to the top predators. Basic productivity is related to distance from land. Runoff through riverine systems brings nutrients to the ocean which are used by phytoplankton - the basis of the food chain. This productivity supports all the higher organisms. Where phytoplankton productivity is high fisheries are very productive. Productivity is highest on the continental shelf near land and on shallow banks further offshore (e.g. Georges Bank, Grand Banks) where nutrients are recycled back into the pelagic system by the benthos. Four major upwelling areas in the world's oceans (off California, Peru, northwest Africa, and the Benguela current off the Atlantic coast of southern Africa) support fisheries. Productivity at these sites is due to streams of cooler nutrient-rich water rising to the surface of the ocean. Climatic changes such as the El Nino, when upwelling is reduced and surface temperatures are warmer, have a dramatic effect on the fisheries.

The cycle of productivity in the Gulf of Maine is influenced by temperature and the structure of the water column. Highest levels of productivity occur in the spring and fall each year. Warming temperature and increased sunlight in the spring causes a phytoplankton bloom. As summer progresses the increased temperature stratifies the water column and a thermocline develops. This is a very sharp temperature difference between the warmer surface water and cold subsurface water. The thermocline inhibits the exchange of nutrients and the surface waters become depleted resulting in much lower production by the phytoplankton. In the fall, seasonal storms and cooling temperatures result in the dissolution of the thermocline and nutrient-rich subsurface water is mixed with surface water creating providing the basis for the fall bloom. Over the winter, the combination of cooler temperatures and reduced light for photosysnthesis results in lower productivity.

Notable exceptions to this scenario are on offshore banks like Georges Bank where strong tidal currents in shallow water prevent the establishment of the seasonal thermocline. The water does not become stratified and productivity continues at a higher level.

Production at all levels above the phytoplankton (zooplankton, ichthyoplankton, invertebrates and fish) is directly related to productivity at the lowest level. Those areas with higher primary and secondary production support larger fisheries.

Stratification of the water column and fisheries production

There are many differing consequences for fisheries which might be attributed to global warming. Some of these effects, such as faster growth rates in fish (Georges Bank cod mature at 2 yrs while those off Labrador mature at 7 yrs) might almost, at first consideration, seem positive. A variety of other effects, such as changes in species distribution or reproductive patterns, loss of habitat by flooding etc. are difficult to assess but will probably result in negative impacts. The only certainty is that there will be change.

A small change in a fundamental physical property of the ecosystem, such as stratification, could have very broad implications for the whole biological realm. Stratification (or the lack of), as described above for the Gulf of Maine, is a major factor in the productivity of ocean systems. Any increase in water temperature which causes a greater degree of stratification, either by increasing the difference between surface and subsurface layers, or lengthening the time period of seasonal stratification, will reduce productivity. There is evidence to suggest that small increases in surface temperature of 1 – 2 degrees can have major negative effects on productivity (see below). Mountain (in press) and others have predicted an increase of 2 – 4 degrees C by the year 2100. A rise of this magnitude could increase stratification by 25 – 50%, which will inhibit mixing of nutrients, alter the amount of light that enters the water, cause the spring bloom to end earlier in the season, cause an increase in the abundance of harmful algal species, and result in more frequent anoxic and hypoxic events.

There has been a period of overall temperature increase in sea surface temperatures along the US west Coast over the last 25 years after a change in oceanic circulation in 1976. While this average temperature increase has been only 1.4 degrees C in the sea surface there has been an 80% reduction in zooplankton densities in comparison to levels found in the period 1950 – 1970. It has been suggested that the increased warming of the surface waters has reduced upwelling of nutrients from below the thermocline. This has led to lower phytoplankton levels the basis of the food chain, which has in turn resulted in lower zooplankton biomass (Roemmich and McGowan, 1995). Correlated with the zooplankton reduction and surface water warming is the decline in the proportion of cooler water species and abundance of many nearshore fish species.

Another reduction in productivity due to climatic change was seen in the Northwest Hawaiian Islands, a chain of reefs and atolls that stretch northwest from the main Hawaiian Islands. Reductions in densities at several trophic levels were documented - including seabirds and monk seals to reef fishes and spiny lobsters (Polovina, et al, 1994) Survival of the both eggs and chicks of the red-footed booby and red-tailed tropicbird decreased by 50 % during the 1980s. Possible cause was the extended time away from the nest adults needed to find food when supplies were scarce. Monk seal pup survival was also reduced and that correlates with the drop in densities (by one third) of reef fishes. The spiny lobster fishery dropped 40% in one year.

The reduction in reef fishes occurred in both fished and unfished areas. Sea birds and seals were not subject to fishing so it appears that these reductions were related to declines in food supply. A change in oceanic conditions around during the 1980s resulted in weaker winter storm winds. With reduced vertical mixing, and therefore fewer nutrients in the photic zone, overall productivity at all levels was lower. (Polovina and Haight, 1999; Trenberth and Hurrell, 1994).

Long-term integrated monitoring.

In the early stages of ocean research, scientists tended to focus on their specialties – be it currents, properties of seawater, sediments, plankton or fish. Studies focused on one aspect of the system or in a limited region are usually restricted to descriptive conclusions and provide little insight to causes. We have become aware of the wide variability in natural systems, even those not subjected to over-fishing. It is only in the last several decades that studies of the broader picture have demonstrated how everything is related. Ocean temperatures and climate are inter-related and these affect productivity in the surface waters, which has a dramatic affect on our fisheries. Variations in physical parameters (temperature etc) and densities of organisms vary seasonally, annually, over decades and longer. It might seem an impossible task (and there are those that argue such) to understand all these variations. The only way to achieve some comprehension of causal mechanisms is by long-term integrative monitoring in which a variety of factors are measured at the same place and the same time (physical and biological properties).

Long-term in this perspective is not simply a year or two. Samples should be taken seasonally each year and continued indefinitely. An example of the value of long-term monitoring in understanding ecosystem dynamics was shown by Dayton et al (1999) with their work in kelp forests off Point Loma on the California coast. A nine-year study period included a cold-water, nutrient-rich La Nina event and a warm-water nutrient-stressed El Nino period. Small-scale patterns in these forests are driven by local processes such as competition, disturbance and dispersal and these processes are also important on broader scales. Larger and more lasting effects however resulted from large-scale, low-frequency episodic changes in nutrients. Nutrient distributions in southern California are strongly affected by density stratification and, occasionally, by uptake and release by phytoplankton. There is a clear relationship between temperature and nutrient concentrations, and the processes that affect density and temperature such as upwelling or downwelling as well as shoaling of isotherms and internal waves. The events termed El Nino and La Nina are major ocean phenomena that affect temperature and nutrients and, as a result, kelp density. Canopy area and harvest varied by a factor of four from the post La Nina high in 1990 to the low of 1992, which was associated with El Nino conditions (Dayton et al., 1999). Even beyond these events, a major review of changes in the kelp canopy over the last century (Tegner et al., 1996, 1997) shows up to two-thirds reductions in standing biomass and stipe carrying capacity since 1957 with most of the changes appearing to have occurred after an oceanographic regime shift in the mid-1970s (Hayward, 1997) which resulted in lower ocean productivity.

One program that is a useful model is the California cooperative fisheries investigation (CalCOFI). Since 1949 quarterly cruises have been conducted to monitor the physics, chemistry, biology, and meteorology of the California Current ecosystem. More than 60 sites are sampled from north of Point Conception to San Diego. Sampling offshore is extended down to a depth of 500 m. Hydrographic and plankton data are distributed to the community without restriction. This excellent long-term times series has provided a basis for the development of models and furthered our understanding of the consequences of climatic events such as El Nino.

We do not have an equivalent data series for the Gulf of Maine. Some large interdisciplinary programs have been initiated in the region such as GLOBEC and ECOHAB. It remains to be seen whether current efforts in the region are sufficient to provide appropriate scientific information for management in a changing climate.

Management

Management of Gulf of Maine fisheries has developed into a major issue. I think we all agree that the process needs to be improved. The possibility exists that the fishing industry could be blamed for changes, which are the result of other processes such as global warming. We need to continue to refine our understanding of the ecosystem through modeling and long-term monitoring studies and provide rapid feedback into the management and industrial sectors. Most commercially important fish populations have undergone large fluctuations in the past under more stable climate conditions. The task of trying to assess stocks under changing environmental conditions is indeed daunting. We do not have an option. We have to at least make an effort. If we can identify changes in the basic ecosystem processes such as circulation, temperature structure and primary productivity we might understand sudden, unexpected or long-term changes in aspects of various fisheries. One useful exercise might be to identify (list) probable effects of increasing temperatures on various components of our fisheries, species by species. This would be based on best current knowledge of their biology and refined as new information comes forward. This would focus our attention on the problem and give management some insight into possible causes when changes occur.

Global warming is a long-term issue and part of it will be the increased frequency of medium-term warm events similar to El Nino. Avoiding damages or collapses of fisheries during these periods will provide sustainable harvests while we address the long-term issue. If our models become sophisticated enough, and some degree of forecasting is possible, there are very significant implications for management. This has been suggested for various species of salmon in the northwest. Catches started in the 1870s and reached a maximum of 93,210 tons in 1936 and have since declined. Catches increased starting in the late 1970s and reached historic high levels of 107,500 t in 1985. They have since declined in the 1990s to the lowest levels in history. The changes reflect changes in abundance, which is now known to respond to climate, as well as impacts of fishing and habitat loss. The sustainable harvest rate is a function of the natural productivity of the stock as well as environmental conditions. Maintaining artificially high harvest rates during low productivity of the ocean system during the 1990s likely resulted in over-fishing and population decline (Beamish et al., 2001). If we could effectively predict events such as El Nino, reductions in harvest during low periods of productivity would avoid population crashes. A report sponsored by NOAA suggests that doubling the number of wild coho salmon allowed to enter coastal streams to spawn and reducing the hatchery production by as much as 75 percent during El Nino conditions could reduce the need for drastic short-term measures (such as closing the commercial and recreational coho fishing seasons).

References

Beamish, R.J, G.A. McFarlane and J.R. King. 2000. Fisheries Climatology: Understanding the lnterannual and Decadal Scale Processes that Regulate British Columbia Fish Populations Naturally. pp. 94-1 39. *In* Fisheries Oceanography: A Science for the New Millennium. T. Parsons and P. Harrison Ieds.I

Beamish, R. J., J. H. Youson, and L. A. Chapman. 2001. Status of the Morrison Creek Western brook lamprey LamDetra riChardsoni in Canada. Report to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Canadian Field Naturalist 115 (4): 573-578.

Dayton P.K., Tegner M.J., Parnell P.E., Edwards P.B. (1992) Temporal and spatial patterns of disturbance and recovery in a kelp forest community. Ecol Monogr 62:421-445.

Hayward, Thomas L. (1997) Pacific Ocean climate change: atmospheric forcing, ocean circulation and ecosystem response. Trends in Ecology and Evolutions 12(4):150-154.

Polovina, J. J., Mitchum, G. T., Graham, N. E., Craig, M. G., Demartini, E. E., and Flint, E. N. 1994. Physical and biological consequences of a climate event in the North Central Pacific. Fish. Ocean. 3, 15-21.

Roemmich, D. and J. McGowan. (1995) Climatic warming and the decline of zooplankton in the California current. Science 267:1324-1326.

Tegner, M.J., P.K. Dayton, P.B. Edwards, K.L. Riser. 1996. Is there evidence for long-term climatic change in southern California kelp forests? CalCOFI Reports 37: 111-126. October.

Tegner, M.J., P.K. Dayton, P.B. Edwards, K.L. Riser. 1997. Large scale, low frequency oceanographic effects on kelp forest succession: a tale of two cohorts.Marine Ecol. Prog. Series 146: 117-134

Trenberth, K.E. and J.W. Hurrell (1994) Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics 9(6):303-319.