LONG-TERM CHANGE IN THE NORTH PACIFIC OCEAN: A CONSIDERATION OF SOME IMPORTANT ISSUES

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INTRODUCTION

This report summarizes the results of a meeting held in La Jolla on October 12–13, 1995, which was organized by Tom Hayward at the request of the CalCOFI Committee. The purpose of the meeting was to consider recent observations of long-term changes taking place in the North Pacific Ocean, and to make recommendations about whether these observations merit a response by CalCOFI.

Meeting participants: Tim Barnett, Tim Baumgartner, Ed Brinton, Dan Cayan, Francisco Chavez, Karen Forney, Doyle Hanan, Tom Hayward, John Hunter, Ron Lynn, John McGowan, Rick Methot, Art Miller, Dean Roemmich, Frank Schwing, Paul Smith, Mia Tegner, and Amy Weinheimer.

The following people provided helpful written input: Alec MacCall, Dave Mackas, Michael Mullin, and Jeff Polovina.

OBSERVATIONS AND MODEL RESULTS

There is no doubt that important changes have been taking place in atmospheric forcing and in the physical and biological structure of the upper layers of the North Pacific Ocean in the past few decades. Zooplankton biomass and the abundance of pelagic fish and squid in the subarctic Pacific were doubled in 1980–89 in comparison with 1956–62 (Brodeur and Ware 1992). There was also a positive correlation between the intensity of winter winds and zooplankton biomass measured during the subsequent summer in the subarctic Pacific. In the subtropical North Pacific, a doubling of the vertically integrated chlorophyll starting in the mid-1970s is associated with a cooling of SST and an increase in winter winds (Venrick et al. 1987). Decade-scale trends in atmospheric pressure patterns, in mixed layer depth, and in the productivity of several trophic levels has been observed in the subtropical North Pacific (Polovina et al. 1994, in press). Macrozooplankton biomass off Peru declined sharply in the mid-1970s (Pauly et al. 1989), and this was associated with an increase in the strength of upwelling-favorable winds (Bakun 1990). In the California Current, a secular rise in coastal sea level in the last few decades is partly due to warming (and hence expansion) in the top 300 m (Roemmich 1992). A decrease in macrozooplankton biomass (Roemmich and McGowan 1995a, b) and in the abundance of pelagic seabirds (Veit et al., in press) in the California Current is associated with a warming of the surface waters and an increase in stratification.

Much progress is being made in describing and modeling the physical structure of the system, at least in terms of understanding what has taken place. For example, isotherms in the thermocline off the western coast of North America were observed (in XBT data) to deepen in the mid-1970s while the mixed layer concurrently shallowed. This shift in basic-state structure was studied by Miller et al. (1994) in a basin-scale model driven by observed heat flux and wind-stress anomalies. New results from the analysis of that model show that the thermocline deepening off the California coast is part of a basin-scale shift in thermocline structure which is driven by a basin-scale change in wind stress curl. A concomitant weakening of the subtropical gyre (by about 10 percent) occurs in the model as well, but with little long-term change in the California Current transport. Definition of scale is an important issue, since shorter-term interannual changes in thermocline structure associated with El Niño provide a large local signal but a finite lifetime for biological response.

Prediction is still some way away, especially on the mesoscale. Models and mechanisms that may link physical and biological structure on the variety of time and spatial scales involved here need to be developed. Such models must include variations in upwelling and nutrient inputs due to interannual changes in the upwelling-favorable wind field (Bakun 1990), variations in the nutrient input due to a secular trend of increasing stratification (Roemmich and McGowan 1995a, b), and variations in primary production associated with interannual changes in mixed layer depth (Polovina et al., in press). Physical models are improving more rapidly than biological models, and it is highly probable that predictive ability in physical structure will precede that in biological structure.

SOME IMPORTANT QUESTIONS

Basic Science versus Policy and Management Issues

Our meeting emphasized basic science over policy and management issues, probably due to the mixture of those in attendance. In spite of this, it was recognized that there is a real need to make the basic scientific findings of long-term change in the California Current accessible to policy makers and managers in a form that is compelling and useful to them. There was discussion that policy and management issues in the coastal region of California generally seem to be focused upon point-source effects and regional anthropogenic change, while the largest changes we have observed in ecosystem structure are those associated with long-term change which are correlated with changes in the large-scale physical structure. There was general consensus that improving our understanding of the basic science issues will lead directly to increased value for management and policy issues. The group also felt that making the scientific and management communities more aware of these issues would help in gaining research support and seeing more practical application of the findings.

How Is Physical Structure Linked to Biological Structure, Both at the Level of Biomass and Species?

An understanding of how physical structure is linked to biological structure is at the heart of understanding the nature of the changes that have taken place in the California Current, and central to predicting future change. Recent studies have suggested that changes in several different aspects of environmental structure, including mixed layer depth, stratification, and the strength of upwelling-favorable winds, are the cause of changes in primary production. These mechanisms assume that changes in, at least, the biomass of higher trophic levels are forced by bottom-up forcing. Although these physical changes are related, they are also conceptually different mechanisms which may have different regional patterns or different time series. Since time series of several aspects of physical structure are correlated with each other, it is difficult to separate causal mechanisms via time series analysis. Furthermore, the effects of in situ, bottom-up forcing may be masked by apparent changes in population size due to advection, changes in range or preferred habitat of mobile species, and top-down forcing (where changes in predator or grazer populations regulate the abundance of the lower trophic levels). Separating these different mechanisms will be a difficult challenge, especially at the level of individual species. Physical-biological model studies could help to sort out these causalities.

Did Species Structure Change during the Period of Declining Macrozooplankton Biomass?

There are really two questions here. What changes took place in species structure of trophic levels (phytoplankton, macrozooplankton)? How did the population size of selected individual species change? When trophic levels or broad categories such as phytoplankton or macrozooplankton are considered, it is unknown whether species structure changed in addition to biomass. For a few individual species, large changes in population size have been documented. However, in these cases it is difficult to know what caused the changes and whether they are related to long-term environmental change. Most of the discussion focused upon the need to know whether species structure of the macrozooplankton changed, because this is an important response of the ecosystem and it may affect the population dynamics and species structure of higher (and lower) trophic levels.

Are the Changes We See Due to Natural Cycles or Global Change?

One of the most important questions is whether the changes in macrozooplankton biomass are part of a natural cycle or due to anthropogenic global warming. The time rate of change is so small that it is unlikely that this question can be answered by direct measurement of changes in rate processes. However, long time series (10^2–10^3 year) preserved in the sedimentary record can be used to extend the temporal coverage of CalCOFI and estimate scales of natural variability. The paleoceanographic record shows that changes of similar magnitude have occurred in the past. For example, deposition rates of sardine scales over the past 2,000 years show interdecadal–century variability of greater magnitude than has occurred since the initiation of CalCOFI (Baumgartner et al. 1992). Improvement in our understanding of how physical structure changed and how it is coupled to biological structure will help to answer this question.

Can the Present Sampling Scheme Be Improved within the Scope of the Currently Available Resources?

Discussion of the CalCOFI sample scheme focused upon the quarterly time-series cruises. The present scheme does a poor job of characterizing the annual pattern of events. It was observed that attempting to fit the cruises into a specific time window leads to a phase lock, which biases construction of a mean annual cycle. Sampling from south to north on the cruises leads to two-week gaps between sampling the southern and northern lines, and the present scheme leads to gaps in ADCP coverage of the perimeter of the pattern. It was suggested (by Roemmich) that the pattern could be modified to sample the perimeter at the end of the cruise; this would have the advantages of complete ADCP coverage and completing the sampling in a few days. This change would greatly improve the ability to construct a control volume (e.g., Roemmich 1989) and constrain fluxes into and out of the sample grid.

It was also observed that changes within the CalCOFI pattern are forced by physical processes on larger scales, and that populations in different regions may respond differently to changes in environmental structure. Collecting time series of similar data at sites off northern California and Baja California would help to provide a larger-scale view of forcing and indicate whether populations respond to change in the same way.

RECOMMENDATIONS

Nine specific recommendations were made at the meeting. In preparing this list we recognized that recommendations had the greatest chance of being implemented if the costs were modest and if some reasonable source of support were feasible. We did not set priorities on the recommendations because we recognized that priorities will vary depending on the enthusiasm of individuals to pursue the recommendations and on funding priorities of the federal agencies. However, we can state that recommendations with the highest priority were 1 and 2, the general areas of improving our understanding of changes at the species level and increasing modeling efforts in physical models and their coupling to biological structure.

1. Improve Resolution of Zooplankton Species Changes

There was general agreement on the need to understand how species structure of at least some of the major components of the macrozooplankton has changed. It was recognized that several approaches to this—such as counting pooled samples, counting selected years or regions, counting only selected taxonomic groups, or scanning for key species—could reduce the effort required to a more manageable level.

2. Start Putting Biology in Physical Models and Test the Relation to See If the Decline in Macrozooplankton Biomass Can Be Reproduced

One way to gain understanding of the processes linking physical and biological structure will be to include biological processes in physical models of the California Current which are now being developed. The macrozooplankton biomass time series will be ideal for testing such models, and the ongoing data collection program can be used to evaluate predictive ability as it evolves. As a first step in the model-testing process, a very simple model of primary productivity was proposed to be studied by using the mixed layer depth changes hindcast by Miller et al. (1994) as the sole input, with the output compared with historical data on ecosystem productivity.

3. Gain Access to the Output of "Operational" Physical Models Being Developed with Navy Resources

A set of "operational" models is being developed and will be used in the future by the navy for an up-to-date estimate of the upper ocean circulation. The navy will use the model output for its own purposes, but does not have plans to distribute or archive the model output. If the navy is willing to release these data, it would be valuable to distribute the output in a timely manner and to archive the data.

4. Establish a Sample Program off Northern California and Baja California

It would be useful to establish CalCOFI-type field programs off northern California and Baja California. Establishing these would require local resources. It is clear that they would not need to be of the same scope as the present CalCOFI program to be valuable, but it is not clear what the minimum number of stations would need to be (especially to understand changes in macrozooplankton species structure). The CalCOFI data could be used to answer this question.

5. Improve Resolution of Annual Pattern

The annual pattern is poorly resolved by the quarterly sampling on the CalCOFI survey cruises. Additional information about the annual cycle comes from the historical data when cruises were more frequent, ship-of-opportunity cruises made by the cooperating agencies and other regional research programs, coastal shore station data, and coastal mooring data. The annual pattern could be better resolved by including other data sets in the analysis and by establishing moorings at a few selected sites.

6. Have a Meeting on CalCOFI Sampling

People at this meeting felt that there was neither time nor the right group of participants to consider the CalCOFI sample scheme in great detail and to make any recommendations for change. It was recommended that a future meeting deal with this issue. Some focused data analysis may be needed prior to such a meeting. The agenda could include (a) consideration of the present CalCOFI cruise sample scheme; (b) location and sample scheme for additional field programs (e.g., northern California, Baja California); (c) coordination of data distribution and analysis with other sample programs; and (d) location and value of moorings.

7. Better Link the Paleo-oceanographic Record to Water-Column and Current Oceanographic Conditions

There was not sufficient time at the meeting to develop specific recommendations on how to do this, but there was a strong sentiment that it is important to calibrate the paleo-oceanographic record with current water-column conditions. This may require the use of sediment traps and water-column sampling coupled with benthic sampling. It was noted that the Marine Life Research Group has recently increased its level of effort in these areas.

8. Retrospective Data Analysis

The group recognized, as have several other meetings, that much more can be learned by analyzing the existing data from the California Current and at larger scales influencing the California Current (e.g., North Pacific). One specific area which was highlighted was the need to determine if the relation between the nutrient concentration (or dissolved oxygen as a proxy) and temperature/salinity structure has varied in the past few decades. This will be important in understanding how changes in upper ocean physical structure might have affected the nutrient input and primary production.

9. Prepare a Group Synthesis Paper

Most at the meeting were surprised to learn about some aspects of the changes which are taking place in the California Current and felt that the oceanographic community is not generally aware of these changes. It was recommended that a synthesis paper be prepared for a major journal. The paper should focus upon describing change in physical, chemical, and biological (biomass and species) structure in the California Current on a range of space and time scales. This paper would be a useful background citation in grant proposals and a general introduction to the issues. There is no reason why this could not be started now.

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