I. Physical, Chemical Environment, Primary Production, Zooplankton and Their Coupling Model Studies

1. The Bering Sea Ecosystem:Current and Proposed Programs Addressing Lower Trophic Level Resposes to Climatic Change

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Abstract

The Bering Sea is among the most productive seas, but the primary productivity regime exhibits extreme spatial and temporal variability, and is extremely episodic over much of the region. Given the variable conditions from year to year, it is important to learn how physical factors influence and control this high productivity in order that the effects of climate variability can be understood. This paper examines a number of issues identified during scientific planning processes and discusses the effectiveness of current research programs in addressing them.

Introduction

The Bering Sea is one of the most productive marine areas in the world. There is, today, a growth of interest in research on the Bering Sea, and the stimulus for this attention is the perception that major changes are underway in the Bering Sea ecosystem - changes which may be connected with human activities and/or global climatic variability. Indeed, there is evidence for change. Since change and adaptation in response to climate is a universal characteristic of ecosystems, the dimensions of this "natural" change need to be resolved before it will be possible to definitively ascribe effects to human activities.

The southeast Bering Sea has had multiple years of oceanographic and fisheries observations, with a great deal of information derived from the work of several nations. This paper emphasizes the outcome of recent research planning within the U.S., although the results of deliberations by the Bering Sea Working Group (WG#5) of the North Pacific Marine Science Organization (PICES) are also considered. It builds on the work of a large number of scientists. Table 1 shows the issues, the source and the programs which address them.

Ecological research by the U.S. in the southeast Bering Sea began in the 1970s with the Outer Continental Shelf Environmental Assessment Program (OSCEAP), followed by the National Science Foundation (NSF)-supported Processes and Resources of the Bering Sea Ecosystem (PROBES) program in the late 1970s and early 1980s. NSF-funded research in the same area spanned, at intervals, the remainder of the 1980s, and now, the Bering Sea Fisheries Oceanography Coordinated Investigation (FOCI) program and the Southeast Bering Sea Carrying Capacity (SEBSCC) program have been implemented. Also, the Arctic Research Initiative is underway and the Bering Sea Impact Studies (BESIS) program is under development. These programs represent just those centered in the U.S., and include only those which incorporate some basic physical, chemical and lower trophic biological oceanographic work. There is also long-term annual cooperative research conducted aboard the Japanese training vessel *Oshoro Maru* (Hokkaido University). Thus, it should now be possible to look at the available information and come to some conclusions about the status of the productivity regime in the southeast Bering Sea shelf. It should also be possible to observe in retrospect how it responds to climatic variability, since the studies just mentioned span years with varying climatic conditions which include so-called regime changes. However, there are gaps in our understanding of how changes in physical processes influence nutrient supply and the nature of lower trophic level responses.

Table 1. Scientific issues and applicable ongoing research program.

Scientific Issue	Source	Research Program	Program Coordination
Sources of nutrients to the southeast Bering Sea shelf and the processes that affect their availability	SEBSCC Plan	SEBSCC Arctic Research Initiative (Green Belt)	Allen Macklin[1)] Gunter Weller[2)]
Water-mass exchange, advection and mixing in the Bering Sea and the influence on bioproductivity	PICES WG#5	SEBSCC	Allen Macklin
The role of variability in sea ice extent and timing as a primary factor influencing productivity	SEBSCC Plan	SEBSCC (Retrospective)	Allen Macklin
Sea-ice dynamics and its influence on bioproductivity	PICES WG#5	SEBSCC (Retrospective)	Allen Macklin
Factors which determine the relative allocation of organic carbon going to benthos versus that remaining in the pelagic system	SEBSCC Plan	SEBSCC	Allen Macklin
The structure of the lower trophic level and energetics on the shelf in summer and winter, especially regarding euphuasiids	PICES WG#5	SEBSCC Arctic Research (Green Belt)	Allen Macklin Gunter Weller

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Approach

The approach in this paper will be, first, to briefly recall the status of our understanding of lower trophic level primary production, and then to examine the major questions developed through recent planning. Finally, the role of current research programs in addressing the questions and some priorities for the future will be discussed.

Background

Previous work on primary production in the Bering Sea has demonstrated the importance of the spring bloom over the southeast Bering Sea shelf (Iverson and Goering, 1979), the role of sea ice melting at marginal ice zones in stabilizing the water column and in initiating the spring bloom (Niebauer and Alexander, 1985) and the role of cross-shelf fronts in the allocation of products of primary production (Iverson et al., 1979; Coachman et al., 1980; Cooney and Coyle, 1982). The spring bloom occurs earlier if sea ice reaches a point over the shelf, since melting ice is more effective in producing water column stability than surface heating at these latitudes (Niebauer et al., 1990). The bloom also is more intensive and short-lived, with extremely high chlorophyll levels, and probably serves to effectively supply energy to the benthic community.

In the middle shelf, most of the products of the spring bloom sink to the bottom, regardless of whether it is a marginal ice zone bloom or a normal spring bloom triggered by thermal stratification. Much of this material remains viable on the bottom for a period on the order of weeks, and possibly contributes to continuing primary production (Alexander et al., 1996). Further out on the shelf, however, it is likely that more of the products of the spring bloom remain in the pelagic region in the case of a thermal-stratification bloom. In the case of an ice-edge bloom, a larger proportion of the products sink. In addition to the effects of the rapid development and intensity of the bloom which does not allow for effective coupling with zooplankton grazing, the low temperature in the surface ice-melt layer discourages copepod grazing (Coyle and Cooney, 1988). 1997 was a year with extensive ice cover, and the early spring bloom at the ice edge removed the surface nutrients and rapidly moved to the bottom over the outer shelf domain (J.J. Goering, Pers. Comm.). This had also occurred in 1975, another extreme ice year. Thus, ice plays a large role in both timing and allocation in years with extensive ice cover. There is a huge variability in the annual extent of sea ice from year to year, which influences temperatures over the Bering Sea shelf during the subsequent summer (Niebauer, 1980; Niebauer, 1983; Niebauer et al., in press). A "cold pool" exists as a residue over the southeast Bering Sea shelf following a winter with extensive ice cover.

Springer et al. (1996) discuss the importance of the flow of nutrient-rich water along the shelf from east to west and its movement northward as the Anadyr stream. This is described as a "Green Belt" of high productivity at all trophic levels, since the high primary production is sustained throughout the year and enhances pelagic, as well as benthic, food chains. The nutrient content of the water flowing along the edge of the shelf, at over 20 *μg-at/l* nitrate, is not fully utilized as the water moves northward through the Bering Sea (Sambrotto et al., 1984). Within this water, high primary production probably occurs throughout the entire ice-free season, adding significantly to the overall productivity of the Bering Sea shelf along a restricted belt, and concentrating biota from a number of trophic levels. As a result, the productivity of some benthic communities overlain by this water stream in the northern Bering Sea is extremely high (Highsmith and Coyle, 1990).

It is clear that the high productivity of the Bering Sea shelf has to do with the juxtaposition of a huge shallow shelf with a deep basin, and with the transport of nutrients from that basin onto or along the shelf. Further, this transport is related to the overall northward movement of water from the North Pacific Ocean onto the shelf and through the Bering Strait northward over the Chukchi Sea shelf. The acceleration of the flow of the Alaska Stream along the outer shelf region, the increase in nutrient transport through tidal mechanisms and the role of eddies are all considered important mechanisms. A prime consideration, then, must be the effect of climatic variability on such transport. The second element relates to the role of sea ice, which is important not just from the production point of view, since in a number of ways it affects the ecological regime. The considerable variability in ice cover must be considered.

Key Scientific Questions

SEBSCC is a program of the Coastal Ocean Program, National Oceanic and Atmospheric Administration (NOAA). It is jointly managed by the Pacific Marine Environmental Laboratory and the Alaska Fisheries Sciences Center of NOAA, and the University of Alaska Fairbanks (UAF). In planning for a five-year research effort for a regional marine ecosystem study, several central scientific issues relating to lower trophic levels were identified. These include the sources of nutrients to the southeast Bering Sea shelf, the processes that affect their availability, the role of variability in sea ice extent and timing as a primary factor influencing productivity, and the factors which determine the relative allocation of organic carbon going to benthos versus that remaining in the pelagic system. There is also a question relating to the structure of the lower trophic level and energetics on the shelf in summer and winter, especially regarding euphuasiids. SEBSCC emphasizes the role of juvenile pollock as a nodal species in the food web, but closely integrates physical, chemical, lower trophic level, higher trophic level and modeling approaches.

PICES established a working group on the Bering Sea (WG#5). The resulting research recommendations included two focal areas, with the recommendation that one of them be developed as a research project: 1) water-mass exchange, advection and mixing in the Bering Sea and the influence on bioproductivity; and 2) research on sea-ice dynamics and its influence on bioproductivity (PICES Annual Report, 1996). Scientific directions recommended by this group agreed with, and reinforced, SEBSCC priorities. They included the roles of decadal scale changes, biological responses to physical-chemical forcing, water mass interchange and formation of deep water.

The Role of Current Programs

A number of the projects underway by SEBSCC are addressing key issues directly among them, retrospective studies of the natural scales of variability in coastal marine ecosystems of the eastern Bering Sea and the role of atmospheric forcing on the cold pool and ecosystem dynamics of the Bering Sea shelf. A retrospective study is currently looking at available information from past studies and examining it in light of contemporary hypotheses. Three projects directly address lower-trophic-level processes: 1) investigation of the origin and dynamics of nutrients on the southeast Bering Sea shelf in relation to dominant physical and biological processes (T. Whitledge); 2) isotopic and biomarker composition of sinking organic matter in the southeast Bering Sea (S. Henrichs); and 3) optical measurements in the southeast Bering Sea (P. Stabeno). These field projects directly address the transport of nutrients onto the shelf and the factors which affect the variability of such transport, and the production, fate and distribution of the primary production products. Work on monitoring and developing biophysical indices of the southeastern Bering Sea by R. Brodeur, G. Hunt, J. Napp, J. Schumacher and P. Stabeno further examines the ecological interrelationships in the region. A remote-sensing study by S. Okkonen is looking at mesoscale eddy-like features. All of these projects address areas central to the major issues.

Bering Sea FOCI was designed to test the hypothesis that transport of larval pollock from the deep Aleutian Basin to the continental shelf contributes to the viability of the U.S. fisheries. Thus, the issue of transport from the basin to the shelf is central to the program. Large scale physical and biological surveys have been initiated, with long-term hydrographic sections and oceanographic moorings. In some respects, FOCI and SEBSCC are complementary. The programs focus directly and heavily on pollock.

A third contributing initiative is the Arctic Research Initiative on the Bering Sea. This is a joint program between NOAA and UAF, managed by the NOAA-UAF Cooperative Institute on Arctic Research (CIFAR). This program began in FY97 and will continue in FY98 - the project focus is on the "Health of the Western Arctic/Bering Sea Ecosystem" (G. Weller, Pers. Comm.). One of the research areas selected is "Natural Variability of the Western Arctic/Bering Sea Ecosystem." Under this umbrella, the program is supporting two major sub-topics: 1) Bering Sea Green Belt processes and ecosystem production; and 2) atmosphere-ice-ocean processes that influence ecosystem variability. No published results are available yet, but clearly these studies address the major issues directly. An international effort which is receiving support within the U.S. is the BESIS project. Originally conceived as a parallel to the International Arctic Science Committeeas (IASC) Barents Sea Impact Studies (BASIS), BESIS began with a series of workshops funded by IASC, NSF and the

U.S. Department of Interior, to address the regional impacts of global change in Alaska and the Bering Sea. This program is intended to be broad and comprehensive, and to include oceanographic, ecological, atmospheric, fisheries and socio-economic considerations, among others. While relevant to Bering Sea productivity, the emphasis will be far broader.

Summary

The questions identified as critical in some of the planning efforts for addressing the causes and means of change in the southeast Bering Sea at the lower trophic levels, are being addressed effectively in some of the ongoing research efforts. In the future, however, it will be necessary to conduct research which spans the international boundary and extend it to the Russian coast, so that the Bering Sea shelf is considered as an integrated unit. A second gap is the lack of research which effectively addresses the interaction between the deep Bering Sea basin and the waters over the shelf. The physical transport of waters onto the shelf and across the shelf break, through submarine canyons and valleys, and through wind-induced shelf break upwelling and eddies, are important processes which influence primary production over the shelf. While to some degree SEBSCC is addressing the research needs (as is the Arctic Research Initiative on the Bering Sea), a great deal more effort will be required before we can determine whether the productivity of the Bering Sea is changing, what the nature of the physical driving forces is, and the ecological implications. Finally, a means of addressing the extremely episodic nature of primary production in the region, as well as the tremendous spatial variability, needs to be considered. Periodic assessment of pigments by aircraft remote sensing is an approach that could be useful, since adequate temporal coverage by at-sea approaches will be difficult to attain.

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