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Author(s)	ESLINGER, David L. ; MILLER, Lawrence J.
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18. Satellite and Modeling Evidence of Bottom-up Impacts on Bering Sea Fish Populations

David L. ESLINGER and Lawrence J. MILLER

Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, Alaska, USA

Abstract

A methodology has been developed for comparing satellite estimates of the distribution of near-surface chlorophyll in the southeastern Bering Sea with measurements of fish biomass from NOAA demersal trawl surveys. Testing of the method with several fish species reveals tantalizing suggestions of the effects of changes in phytoplankton biomass on fish biomass and distribution. A coupled physical-biological numerical model has been developed for the Bering Sea and for Prince William Sound, AK. This model is used to examine the effects of physical forcing on lower trophic levels, with implications for higher trophic levels. The model analysis identifies the mechanisms by which the relationships suggested in the satellite analysis could occur, and illustrates the small changes in physical forcing that would be required to create them.

Introduction

The waters surrounding Alaska are of major importance in the U.S. and foreign fisheries. In recent years, over 50 percent, by weight, of the U.S. commercial fisheries landings occurred in Alaska and represented over 38 percent of the monetary value of the U.S. fishery (U.S. DOC, 1996a). These fisheries occur in both the Bering Sea and the Gulf of Alaska, as illustrated by Dutch Harbor-Unalaska, AK (in the Bering Sea) and Kodiak, AK (in the Gulf of Alaska) being the leading U.S. ports in terms of both quantity and value of commercial landings in 1995 (U.S. DOC, 1996a). Alaskan fisheries are of national and international importance. Forty-five percent of the total U.S. seafood exported is from Alaskan ports, and another 34 percent is from Seattle (UAA, 1996), much of which is from Gulf of Alaskan fisheries. Japan is the major importer of Alaskan fish products and accounts for over 90 percent of the Alaska seafood exports (UAA, 1996).

Alaskan waters are thought to be some of the most productive in the world (Hood and Kelly, 1979), and have been the focus of several extensive, multi-year research programs: i.e., Outer Continental Shelf Environmental Assessment Program, OCSEAP (OCSEAP, 1986); Processes and Resources of the Bering Sea Shelf, PROBES, (McRoy et al., 1986); Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas, ISHTAR (McRoy, 1993); and the ongoing Fisheries-Oceanography Coordinated Investigations, FOCI (Kendall et al., 1996). However, due in part to the enormous distances, severe weather, and expenses involved, the regions are still not well understood (NRC, 1995) and remain the

focus of ongoing studies (e.g., U.S. DOC, 1996b).

Because of the dynamic nature of the ecosystems, the scale of the regions involved, and their high latitudes, they seem ideal candidates for studies utilizing satellite remote sensing. Several new ocean color satellites are now operating (SeaWiFS and MOS) and others are scheduled for launch in the near future (e.g. MODIS, ADEOS-II). These instruments will provide us with data on near-surface chlorophyll concentrations in the Bering Sea. Measurements of sea surface temperature have been available for some time from the NOAA AVHRR instruments. The NOAA National Marine Fisheries conducts yearly trawl surveys of demersal fauna in the southeastern Bering sea. These data show significant variations in the distribution and biomass of many species. The reasons for this variation are not well understood. In the present study, we discuss the impacts of variations at lower trophic levels on fish stocks (bottom-up effects) which are suggested by comparing satellite data and fish biomass. In addition, we present results of a numerical model which illustrates the mechanisms by which changes in the physical environment could propagate through phytoplankton and zooplankton into higher trophic levels.

Satellite and Trawl Analysis

As we collect more, and different types of, satellite data, one of the challenges facing us is to combine satellite data with conventional shipboard observations to increase our scientific understanding. A method of comparing Coastal Zone Color Scanner (CZCS) imagery with estimates of fish biomass from NOAA demersal trawl surveys has been developed (Miller, 1998). In the present study, we will focus on comparisons of ocean color and sea surface temperature with biomass of walleye pollock (*Theragra chalcogramma*), yellowfin sole (*Pleuronectes aspera*), and Pacific cod (*Gadus macrocephalus*).

Trawl results and CZCS chlorophyll distributions were binned into 0.5x0.5 degree bins. Annual averages were created for 1979 through 1986 when data were available. An empirical orthogonal function (EOF) analysis was performed on the annual averages, corrected for missing values (Eslinger et al., 1989). The EOF analysis reveals the long-term average distributions of fish and phytoplankton biomass and time series of the anomalies of the yearly averages from the grand mean. Time series of chlorophyll and fish biomass were generally similar, showing a period of low biomass early in the study period, increasing through the middle portion, and a decrease toward the end of the period. We suggest that one explanation for the similarity in the basin-wide biomass time series is that fish populations are responding to increases in available food, which is a result of increased phytoplankton biomass. We recognize that there are other factors that are also important, but wish to examine the bottom-up hypothesis. The largest EOF's for chlorophyll and fish biomass also suggest that there can be spatial differences in fish biomass in response to differences in chlorophyll distribution between years.

Satellite-derived sea surface temperatures were only available for the last half of the

study period. They indicate that springtime temperatures were more variable in the years with high biomass. This physical variability could provide a mechanism for increased phytoplankton productivity, which may then lead to an increase in zooplankton and other potential food species. The mechanisms behind the zooplankton response are described in the modeling section below.

Modeling Analysis

The coupled biophysical model used in this study is a major expansion of a spring diatom bloom model of Eslinger and Iverson (in press). The significant features of the Eslinger-Iverson model retained in our model are the high vertical resolution, 2 meters, and the realistic mixed-layer dynamics. We modified the Eslinger-Iverson model to apply to annual time periods by increasing the number and complexity of the chemical and biological processes included in the model. We have added ammonium and silicon dynamics; a flagellate component; three types of zooplankton: large *Neocalanus*-type copepods, smaller *Pseudocalanus*-type copepods, and euphausiids; and an unspecified carnivorous nekton component which preys upon the zooplankton. This model is run for Prince William Sound, Alaska, which is at a similar latitude and has similar flora and fauna as the Bering Sea. We expect the model results to hold for Bering Sea as they do for Prince William Sound.

The model has been run for five years for which field data are available. The model reproduces field phytoplankton and zooplankton biomass very well. The magnitude and timing of the spring blooms are well simulated. Model results indicate that small changes in meteorology during early spring produce differences in the timing and duration of the spring phytoplankton blooms, which in turn lead to large differences (a factor of 5-8 times) in zooplankton biomass that persists throughout the rest of the year. In addition, differences in springtime meteorology lead to differences in the amount of primary production which reaches the benthos, as opposed to staying in the pelagic food web. A sensitivity analysis reveals that small differences, say only a couple of degrees of difference in initial water temp, or a 10% difference in wind speed, is enough to produce the very large differences seen in field data..

Discussion & Summary

From the field data and biological model response, springs can be divided into two types: quiescent, or stormy. During a quiescent spring, stratification occurs rapidly and a short intense spring phytoplankton bloom occurs. Subsequent zooplankton production is minimal and much of the new production sinks to the benthos. During a stormy spring, in contrast, stratification is intermittent and the alternate stratification and mixing of the surface waters slows down the spring phytoplankton bloom. Zooplankton can take full advantage of this slower bloom, and a large pelagic zooplankton biomass is supported. A smaller percentage of new production reaches the benthos. In addition, the eventual depth of

summertime stratification is increased by a stormy spring, resulting in more new production. Increased new production may lead to increased fish biomass due to the additional organic mater which is available. In the analysis of phytoplankton and fish biomass, there was increased variability of springtime sea surface temperatures during the years in which springtime phytoplankton biomass appeared highest. This is consistent with a stormy, variable spring leading to increased phytoplankton and zooplankton biomass, as observed in the model results and in Prince William Sound field data. We recognize that this is only one piece of the puzzle we face in trying to understand the variability in fish stocks in the Bering Sea, but feel that it is worth further discussion and study.

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